2004 and 2005 Phase II Studies
KNIGHTS FERRY GRAVEL REPLENISHMENT PROJECT

Produced for

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EXECUTIVE SUMMARY

The Knights Ferry Gravel Replenishment Project (KFGRP) was originally implemented by Carl Mesick Consultants (CMC) from 1998 to 2000 and funded by CALFED. It was designed to investigate the hypothesis that adding cleaned spawning gravels to streambeds will increase production of healthy juvenile fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Stanislaus River and to determine why few Chinook salmon spawned in previously restored spawning beds in the Stanislaus River. Phase II of the KFGRP was implemented by KDH Environmental Services in 2004 and 2005 to conduct Chinook salmon egg survival studies and to continue the studies of spawner use relative to gravel source and size distribution.

A majority of the data collection for the Phase II project occurred in fall 2004; whereas the fall 2005 work focused on the egg survival to emergence studies. However, the fall 2005 studies were not successful because flood control releases scoured away many of the egg incubation chambers and deposited a large amount of fine sediment in the remaining egg chambers.

Overall, the Phase II studies indicate that the construction of spawning beds for fall-run Chinook salmon with clean spawning gravels in the Stanislaus River provides short-term benefits for spawning and egg incubation and perhaps longer term reductions in fry entombment that would otherwise be caused by excessive amounts of fine sediments (< 2 mm). The reduction in habitat quality was probably caused by the gradual armoring of the streambed's surface (loss of smaller particles) as well as fine sediment intrusion that compacted the spawning beds. Most of the habitat degradation occurred between fall 2000 and fall 2004 when no flood control releases were made below Goodwin Dam.

Specific analyses suggest that adding gravel cleaned with a 1-inch screen could substantially reduce egg survival rates and adding gravel from other watersheds (e.g., Tuolumne River) could immediately degrade the spawning habitat, although the detrimental effects of using non-native gravels were not apparent after 12 months. The most likely explanation for the near zero egg survival rates that occurred in gravel cleaned with a 1-inch screen is that the interstitial spaces were abnormally large which allowed the eggs to be excessively agitated at relatively moderate intragravel flow rates.

The egg survival studies also suggest that egg survival in the downstream reaches may have been reduced by the combined effects of near lethal water temperatures that fluctuated greatly in early November, excessive fines that reduce dissolved oxygen concentrations, and intragravel turbidity that presumably coated the eggs with clay-sized particles that reduced the egg's abilities to absorb oxygen. A recommendation was made to study the effects of water temperature, turbidity, D.O. concentration, percentage of fine sediments, gravel size (interstitial pore size in the streambed), and intragravel flow rates on the survival of fall-run Chinook salmon eggs under controlled laboratory conditions.

INTRODUCTION

Presented herein are the results of the fall 2004 and fall 2005 Phase II studies for the Knights Ferry Gravel Replenishment Project (KFGRP). The KFGRP was originally implemented by Carl Mesick Consultants (CMC) from 1998 to 2000 and funded by CALFED. The original CMC project was designed to investigate the hypothesis that adding cleaned spawning gravels to streambeds will increase production of healthy juvenile fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the Stanislaus River and to determine why few Chinook salmon spawned in previously restored spawning beds in the Stanislaus River. Phase II of the KFGRP was implemented by KDH Environmental Services in 2004 and 2005 to conduct Chinook salmon egg survival studies and to continue the studies of spawner use relative to gravel source and size distribution.

Pre-project studies conducted from 1994 to 1997 indicated that fall-run Chinook salmon in the Stanislaus River primarily spawned in a 6-mile reach immediately downstream of Goodwin Dam; whereas few spawned in the remainder of the 26-mile long spawning reach (CMC 1996, Mesick 2001). The spawning habitat in the Stanislaus River was highly degraded primarily due to gravel mining that excavated numerous gravel beds from the spawning reach (CMC 2002a) and from excessive sedimentation (DWR 1994, CMC 2001) that reduced intragravel dissolved oxygen (D.O.) concentrations in redds particularly in the downstream areas (Mesick 2001, CMC 2001).

For Phase I of the KFGRP, CMC selected 18 restoration sites and seven naturally occurring control sites in the 18-mile reach between Goodwin Dam (rivermile 58) and the City of Oakdale (RM 40; Figure 1). Pre-project monitoring was conducted in fall 1998 to document the spawning habitat conditions and spawner use at the 25 project and control sites (CMC 2001). In August 1999, a total of 13,000 tons of gravel was placed at the 18 project sites. Three types of gravel were placed at the 18 restoration sites including Stanislaus River gravel cleaned with either a 1/4-inch or a 3/8-inch screen, and Tuolumne River gravel cleaned with a 3/8-inch screen. In fall 1999 and fall 2000, CMC monitored the post-project spawning habitat conditions and spawner use at the 25 study sites. Indices of spawner habitat quality that were studied in artificial and actual redds at each of the study sites included streambed permeability, intragravel D.O., vertical hydraulic gradient, and intragravel water temperature (CMC 2001, 2002b, 2002c). In fall 2000, intragravel apparent velocity was measured with a KVA Model 40L Geoflo Groundwater Flowmeter at the artificial redds (CMC 2002c).

The initial CMC (2002b) studies demonstrated that fall-run Chinook salmon will spawn immediately at the tails of pools constructed with newly placed, cleaned gravel. The results also indicated that salmon redd densities were significantly higher in gravel obtained from the Stanislaus River's floodplain compared to similarly-sized gravel imported from the Tuolumne River's floodplain probably because salmon spawn preferentially in riffles with a scent and mineral content most like gravel from their native watersheds (CMC 2002b). Redd densities were also higher in Stanislaus River gravel cleaned with a 1/4-inch screen compared to gravel cleaned with a 3/8-inch screen, although the difference was not statistically significant (CMC 2002b). This result was likely due to the greater relative ease of digging redds in smaller 1/4-inch substrates versus 3/8-inch substrates. Compared to post-project conditions in fall 1999, the number of redds observed at all three types of restoration gravel in fall 2000 was a significant increase relative to the redd densities at control sites (CMC 2002c). This result suggests that all three types of restoration gravel became increasingly more suitable for spawning by Chinook salmon 12 months after placement.

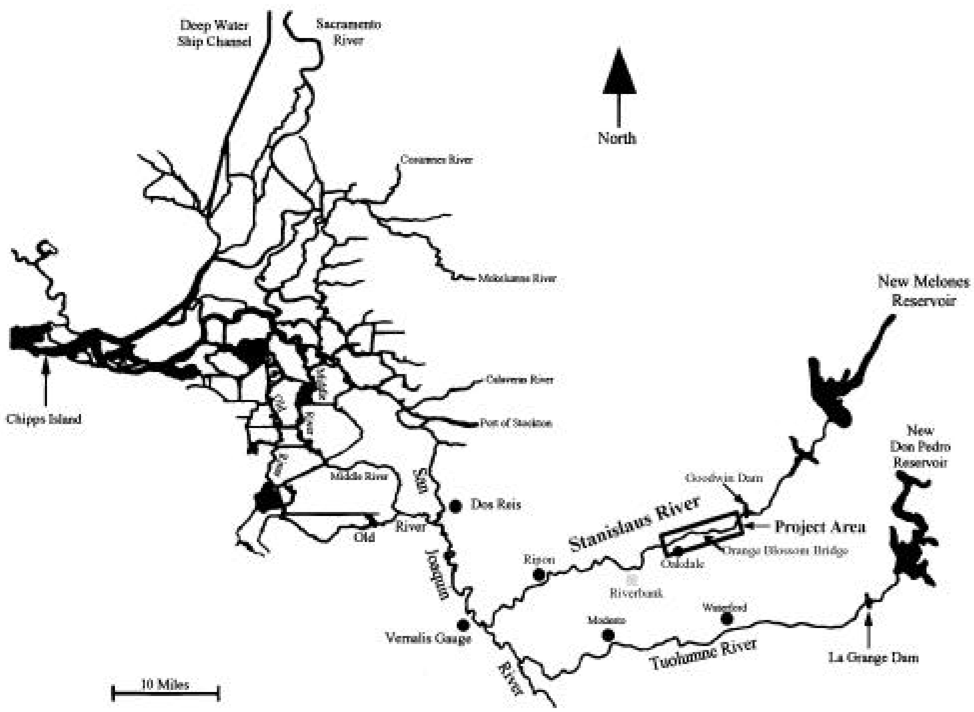


Figure 1. Map of the Sacramento-San Joaquin Delta showing the Stanislaus River, Goodwin Dam, and the project area.

In regard to the study of the environmental factors that affect egg survival during the initial CMC studies, intragravel D.O. levels and permeability in artificial and natural Chinook salmon redds were found to be significantly higher in restoration sites than in control sites (CMC 2002b, 2002c). However, there is a substantial amount of uncertainty in evaluating egg survival to emergence using measurements of environmental parameters alone (CMC 2002b). Furthermore, the estimated total abundance of juvenile salmon passing a calibrated rotary screw trap at Oakdale (RM 40) increased by about 45% for the first two years after the spawning beds had been constructed but then declined to pre-project levels during the next four out of five years (Figure 2); it was not possible to conduct a statistical analysis because there is an insufficient number of pre-project estimates of juvenile salmon abundance.

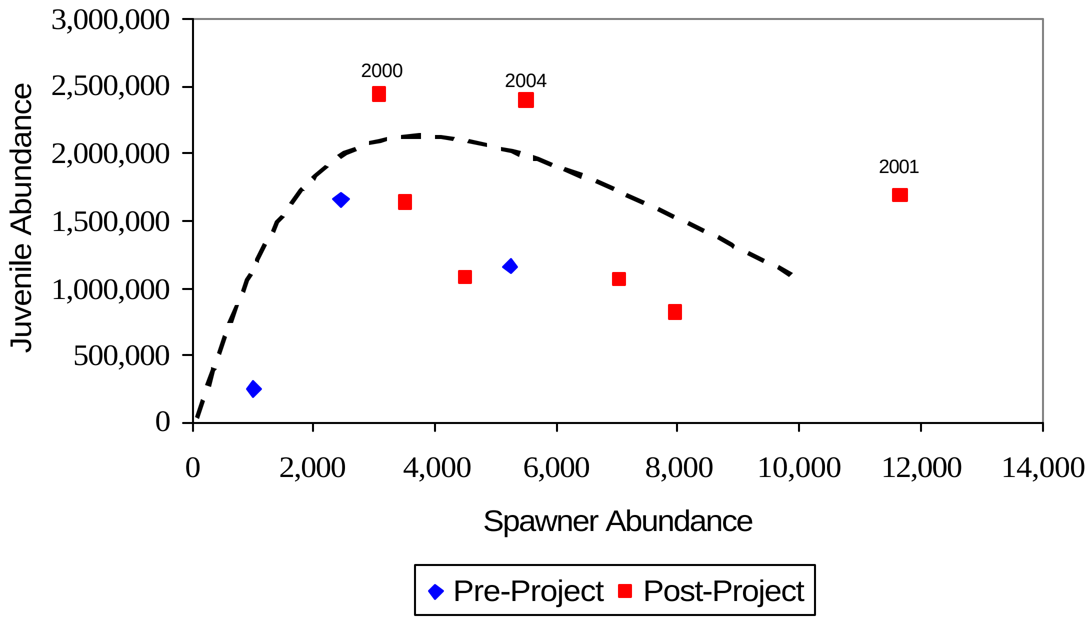


Figure **2**. The relationship between the estimated total number of juvenile fall-run Chinook salmon passing the Oakdale screw trap (RM 40) and the Age 3 equivalent number of spawners during pre-project (1996, 1998, 1999) and post-project conditions (2000 to 2006) in the Stanislaus River. The three highest juvenile production estimates occurred in spring 2000, 2001, and 2004 as labeled. The dashed line shows a Ricker-type relationship between stock (spawner abundance) and recruitment (offspring that survive to the adult stage). The rotary screw trap data was provided by Cramer Fish Sciences and the abundance estimates were generated by Dr. Carl Mesick.

The objectives of the Phase II KFGRP studies were to (1) better understand the influence of environmental parameters such as gravel size, intragravel D.O., and intragravel flow on the survival to emergence of Chinook salmon eggs and (2) continue the evaluation of the effects of gravel source and gravel size distribution on spawner use. In fall 2004 and fall 2005, KDH Environmental Services studied the survival to emergence of newly fertilized (a.k.a., green and pre-eyed), water hardened Chinook salmon eggs at four KFGRP restoration sites, one KFGRP control site, and a restoration site constructed with gravel cleaned with a 1-inch screen by the California Department of Fish and Game and the U.S. Bureau of Reclamation at the tail of the "Float Tube Pool" immediately downstream of Goodwin Dam (RM 58) during summer 2004. There was a concern that gravel cleaned with a 1-inch screen would have high intragravel flow rates and it is possible that excessive agitation from high flows might kill highly sensitive pre-eyed eggs. Hatchery workers are well aware that agitation can kill pre-eyed eggs (Leitritz 1959) and mortality rates are high for salmonid eggs planted in large gravels or marbles in Whitlock-Vibert boxes compared to those planted in gravels with a more natural size distribution (Reiser 2004).

The Phase II KFGRP studies evaluated seven hypotheses:

Hypothesis 1: *Chinook salmon spawners prefer to use native Stanislaus River rock compared to imported rock from the Tuolumne River*. In fall 2004, this study element focused on whether the restoration gravels that were imported from the Tuolumne River would continue to "season" such that eventually there might be no significant differences in redd densities due to the source of gravel.

Hypothesis 2: *Chinook salmon spawners prefer to use gravel cleaned with a 1/4-inch screen and a 5-inch grizzly compared to gravel cleaned with a 3/8-inch and a 5-inch grizzly*. In fall 2004, this study element focused on whether gradual fine sediment intrusion would affect the two KFGRP gravel mixtures differently and thereby gradually change spawner use.

Hypothesis 3. *Adding gravel without fines to the streambed increases intragravel D.O. concentrations and intragravel flow rates compared to those at the control riffles*. This study element evaluated the effects of five years of fine sediment intrusion on intragravel conditions at the 18 KFGRP restoration riffles in the Stanislaus River.

Hypothesis 4. *Restoring riffle habitat with clean gravel will increase egg survival and the size of fry compared to control riffles*. This study element directly measured Chinook salmon egg survival to emergence rates in three different restoration gravel mixtures (1/4-inch, 3/8-inch, and 1-inch screens) and a natural control site. The results were modeled relative to the key intragravel habitat conditions related to D.O, apparent velocity, streambed permeability, substrate particle size distribution, water temperature, and turbidity.

Hypothesis 5. *Entombment of fry is significantly greater at superimposed redds than in non-superimposed redds*. This study element focused on whether the lack of fines in restoration gravels and the greater availability of highly suitable spawning habitat at restoration sites would result in lower fry entombment rates.

Hypothesis 6. *Survival is significantly lower for eggs exposed to turbid storm runoff*. There is almost no information about whether clay-sized particles in turbid storm runoff would suffocate incubating salmon eggs (CMC 2001). The downstream KFGRP sites are exposed to a greater level of turbid storm runoff than the upstream sites. In addition, storm runoff was typically greater during the latter part of the egg incubation period than during the initial egg incubation period. This study element evaluated whether egg survival differed between the upstream and downstream sites and between early planted and late planted egg lots. It also attempted to quantify intragravel turbidity levels during the egg incubation period.

Hypothesis 7. *Riffles constructed in widened, mined channels will have a longer useful life than will riffles constructed in narrow unmined channels*. This study element determined the amount of gravel that has been scoured from the KFGRP restoration sites between fall 2000 and fall 2004. The other study elements evaluated how fine sediment intrusion affected the quality of the restoration gravel.

METHODS

A majority of the data collection for the Phase II project occurred in fall 2004; whereas the fall 2005 work focused on the egg survival to emergence studies. However, the fall 2005 studies were not successful because flood control releases scoured away many of the egg incubation chambers and deposited a large amount of fine sediment in the remaining egg chambers.

To test the seven hypotheses, the following data were collected during fall 2004:

1. periodic surveys to map fall-run Chinook salmon redds;
2. streambed elevation and contour mapping at the 18 project sites;
3. substrate permeability in the undisturbed streambed and artificial and actual salmon redds;
4. periodic measurements of apparent velocity in artificial salmon redds;
5. periodic measurements of intragravel D.O. concentration in artificial salmon redds;
6. intragravel water temperatures in artificial redds measured in 30 minute increments;
7. redd excavations to evaluate fry entombment; and
8. egg survival to emergence at four project sites, one DFG project site, and one control site.

STUDY AREA

The 18 project sites where gravel was added in August 1998 and the seven original control riffles are shown on the USGS quadrangle maps in Appendix 1. In fall 2000 and 2004, three additional control riffles were selected to provide additional estimates of redd density and permeability measurements at redds and undisturbed gravel. Streambed elevation and contour mapping was not conducted at these additional control sites. These additional riffles included Riffle R2, which is upstream of the heavy turbid storm runoff, Riffle R26, which is in an unmined reach directly downstream from Willms Pond, and Riffle R44, which usually receives highly turbid storm runoff as did all riffles downstream of the Orange Blossom Bridge. The locations of these three riffles are shown in the Appendix 1 maps.

SPAWNER USE SURVEYS

At each of the 28 study sites, Chinook salmon redds were identified as oval disturbances in the substrate during three surveys and a partial survey (# 2.5) in fall 2004:

1. Survey 1 - November 5 and 6, 2004
2. Survey 2 - November 14 and 15, 2004
3. Partial Survey 2.5 - November 18, 2004; and
4. Survey 3 – November 23 and 24, 2004.

It is likely that about 85% of the redds would have been observed by the final survey on November 24, 2004. The Cramer Fish Sciences counting weir at Ripon indicated that 3,801 adult salmon had passed the weir by November 14th whereas only 605 additional adult fall-run salmon passed after that date. Chinook salmon in the Stanislaus River typically begin constructing their redds within 10 days after entering the spawning reach based on a comparison of the timing of when the salmon pass the weir at Ripon and the timing of redd construction.

Dr. Mesick supervised all of the spawner use surveys. Salmon redds in the Stanislaus River typically have a shallow pit or depression in the upstream half of the disturbed area and a mound of gravel at the downstream half of the disturbance called a tailspill. Most redds were approximately five feet wide by 10 feet long. Redd locations were mapped at each riffle by means of reference to either 2-foot long reinforcing bars driven into the ground or nails driven into trees on both sides of the river. A transect was established at each riffle by running a tape measure from the pin on the left bank (facing downstream) to the one on the right bank during all surveys. A second tape measure was then run from the redd's tailspill to the transect so that both tape measures were perpendicular to each other. The distance in feet from the pin on the left bank along the transect to the tape measure from the redd was recorded as the station. The distance in feet from the redd to the transect and the direction (upstream or downstream) from the transect were also recorded. The redd coordinates were plotted on a contour map of each site made from streambed elevation measurements made in September 2004. The maps generated from each survey were used during the subsequent surveys to help distinguish between redds that had already been counted and newly constructed redds. Chinook salmon spend between 4 and 25 days guarding their redds (Healey 1991) and so it was assumed that continued redd activity at the same redd location for consecutive surveys were assumed to be the same redd and not a superimposed redd. The location of each of the identified redds and the survey number when the redds were first observed (e.g., R3, which indicates a redd observed during the 3rd survey) are marked on the site maps in Appendix 3.

STREAMBED ELEVATION AND CONTOUR MAPPING

Streambed elevations were measured between September 20 and 28, 2004 at the 18 KFGRP project sites to assess the volume of gravel mobilized during the five years following streambed elevation measurements taken by CMC in September 2000. KDH staff worked with Dr. Mesick to map streambed elevations with a Nikon DTM-310 total station using the same methods described in CMC (2002c).

Elevations of the tops of two to four 18-inch long, 3/4-inch diameter steel rods driven into the ground in August and September 1999 were measured at each site as reference points. At some sites, additional reference points were added in September 2000, whenever the original reference points were missing. These reference points, which are called backsights in the maps in Appendix 3, permitted comparisons of data sets between fall 2000 and fall 2004. Many of the reference points were missing in fall 2004 although at least 1 remained at every site except Riffle R57. Due to the absence of any reference points at R57, it was not possible to evaluate changes in bed elevation compared to conditions in fall 2000.

The Nikon total station has an angle accuracy of five seconds, which provides elevation measurements accurate to within 0.03 inches at a distance of 100 feet. The elevation data were collected as X, Y, Z coordinates that were stored electronically within the total station and then downloaded to a laptop computer. A software program called ATransit@ was then used to convert the data into AutoCAD DXF format files. The DXF files were then imported into a software program called Terrain Version 3.127 developed by *Softree Technical Systems Inc*. to generate the contour maps in one-foot intervals. The contour maps show the location of the transects established in November 1998 and a few additional transects established at project sites in late

August and September 1999 that were needed to provide measurements over the newly placed gravel (Appendix 3). Measurements were taken at five foot intervals along these transects as was done during the previous surveys.

All elevations measured under pre-project and post-project conditions were adjusted to correspond to the height of the measurements of the reference points recorded in December 1999. Therefore, the fall 2004 bed elevations shown in Appendix 3 are directly comparable to the maps shown in the previous study reports (CMC 2002b, 2002c).

To determine the volume of gravel mobilized from the project sites between fall 2000 and fall 2004, the Terrain models for each site were compared between years using the Terrain software. First, the x,y, and z data for each model were adjusted so that the coordinates for the reference points for the September 2004 model matched those for the September 2000 model. Then the Terrain software was used to estimate the volume of material in the September 2004 model that is either above (fill) or below (cut) the surface of the September 2000 model. The volume of gravel mobilized was computed by subtracting the volume of fill from the volume of cut.

EGG SURVIVAL TO EMERGENCE

To test hypotheses four and six**,** water-hardened Chinook salmon eggs from the Merced River Hatchery were buried in five artificial redds in each of the six study sites located in three different reaches on November 8 and 12, 2004 (Figure 3):

1. Goodwin Canyon, which is immediately downstream of Goodwin Dam, where turbid storm runoff is low. Project riffle DFG 1 was studied to evaluate the effects of cleaning gravel with a 1-inch screen. Gravel was added to this site in summer 2004.
2. Lovers Leap, which is about 6 miles below Goodwin Dam where turbid storm runoff was low in 1999 and 2000. Two project riffles, R19 and R19A were studied to evaluate the effects of cleaning gravel with a 1/4-inch and a 3/8-inch screen, respectively. A control riffle, R20, was one of the most highly used natural gravel beds by Chinook salmon spawners in the Stanislaus River.
3. Valley Oak, which is about 14 miles below Goodwin Dam where turbid storm runoff was high in 1999 and 2000. Two project riffles, R57 and R58 had restoration gravels that were cleaned with 3/8-inch and a 1/4-inch screens, respectively. These sites were primarily selected to evaluate the effects of turbid storm runoff.

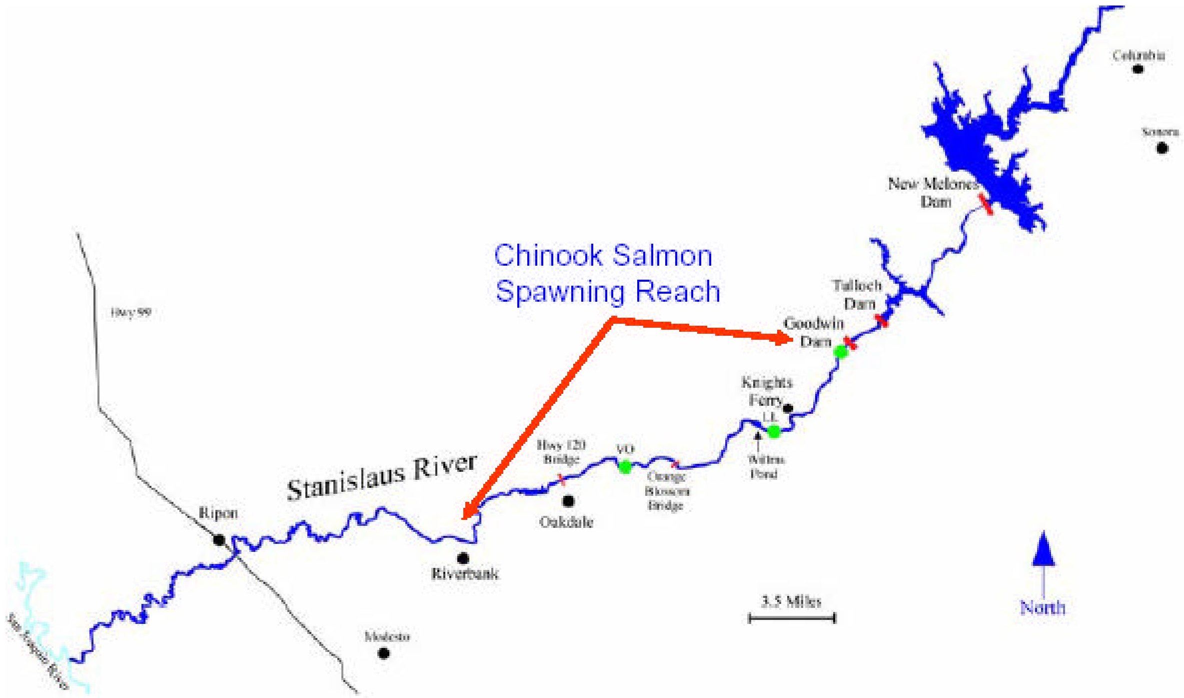


Figure 3. Location of the three egg survival study reaches (green dots), which include Goodwin Canyon, Lovers Leap (LL), and Valley Oak (VO), within the Chinook salmon spawning reach in the Stanislaus River.

A second batch of eggs was planted on December 2, 2004 at riffles 19A and 57 to further evaluate the effects of late-season turbid storm runoff. Five artificial redds were constructed in each of these sites.

To facilitate the rapid placement of the green eggs into the artificial redds, the redds were prepared before the eggs were obtained by burying 8-inch diameter placement pipes that held a "place" for the 6-inch diameter egg incubation chambers and were then later removed (Figure 4). This was necessary because newly fertilized (a.k.a, green) eggs can only be handled safely for 24 to 36 hours after they have become water hardened. Using this method it was possible to plant the egg incubation chambers within 6 hours after they were water hardened.

Figure 4. Place holder pipe with removal ropes, egg chamber with black rubber caps, and apparent velocity well screen with a mini-standpipe that was buried in the artificial redds for the KFGRP fall 2004 egg survival studies.

The artificial redds were constructed by first digging an 18-inch deep hole that was about 10 inches wide at the bottom with hand-held shovels. One 8-inch diameter placement pipe that was 17 inches long was capped at the upper end with a plastic sheet and buried vertically in the gravel in each redd. To collect data on intragravel flow rates, D.O. concentrations, and water temperature in the vicinity of the eggs, three sampling devices: (1) a 19-inch long, 2-inch diameter well screen (Figure 4), (2) a mini-standpipe (Figure 4), and (3) an Onset tidbit thermograph, were buried immediately adjacent to the incubation chamber placement pipe. The 8-inch placement pipe and the three sampling devices were buried in clean gravel that formed a 10-inch high tailspill. The gravel was cleaned by releasing hand-held shovel-fulls of gravel near the water's surface and over the artificial redd and letting the gravel gradually drop onto the redd allowing the water's flow to flush away the fine sediment. When the redd was finished, only a 1-foot long clear plastic tube attached to the mini-standpipe and the uppermost 2 inches of the 2-inch diameter well screen, which was painted with camouflage colors, protruded above the gravel's surface. The incubation chamber was then completely concealed within the artificial redd.

Egg Placement

Immediately after the eggs were fertilized, they were water hardened in an iodine solution at the hatchery for about 90 minutes. Then the eggs were placed in moist scrim cloth bags, which is a cheese cloth like fabric that was provided by the hatchery, within troughs of flowing river water under dim light (Figure 5). The eggs were not individually counted to minimize mortality due to handling. Instead, each cloth bag was filled with the eggs that could be fit snugly to the top of a

78.86-ml (1/3-cup) stainless steel measuring cup (Figure 6). The eggs were allowed to float out of the cup into the cloth bag and never poured to minimize mortality from shock. During the transport from the hatchery to the study sites, which took about 90 minutes, the eggs were kept in an *Engel* portable 12-volt cooler that was maintained between 50 and 52 degrees Fahrenheit (Figure 7), which was close to the temperature of the river water. The temperature in the cooler was monitored with an *Engel* digital thermometer that had a remote thermistor placed in the center of the egg lots. The bottom of the cooler was lined with a wet cloth towel to cushion the eggs and help keep them moist but not submerged under water. The bags of eggs were placed in single layers separated with two sheets of wet paper towels. A 1-inch layer of crushed ice was placed over the top layer of paper towels to help maintain the temperature and provide a source of water slowly dripping over the eggs. The temperature was controlled by unplugging the cooler whenever the temperature dropped to 50.5 degrees and plugging it into a 12-volt source when the temperature increased to 51.5 degrees. The eggs were kept out of the direct light except for the few seconds that it took to transfer the bag of eggs from an enclosed cooler to the egg incubation chamber held in the river.

To evaluate the viability of the eggs from each of the three female salmon used for this study, a sample of at least 2,000 eggs from each female salmon were incubated at the hatchery. This was particularly useful, because few if any of the eggs would show indications that the egg batch was not viable (e.g., an opaque white appearance) until after the chambers had been buried in the artificial redds. This was the case for an attempt to plant eggs on November 4, 2004 that failed. About 66% of the eggs held at the hatchery turned white by the next morning after the eggs had been buried in the artificial redds.

Figure 5. Scrim cloth bags each containing about 220 fall-run Chinook salmon eggs.

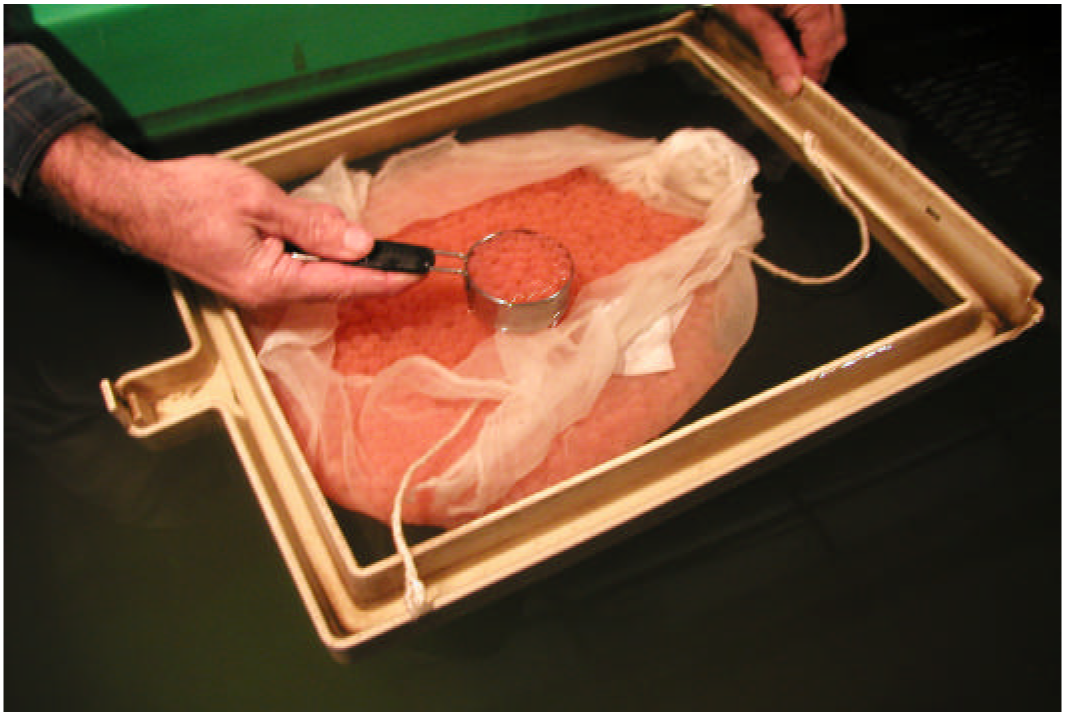


Figure 6. Measuring 78.86 milliliters (1/3 cup) of Chinook salmon eggs, which contained between 199 and 323 eggs, with a stainless steel measuring cup in a flowing water trough in a dimly lit, hatchery building.

Figure 7. Chinook salmon eggs were transported in an Engel portable 12-volt cooler and the temperature was maintained between 50 and 52 degrees Fahrenheit.

Each egg incubation chamber consisted of a 17-inch long, 6-inch diameter, schedule 40 well screen PVC pipe with 0.080-inch (2-mm) slots (Figure 4). The well screen pipe was capped at both ends with 3-mm holes perforated over the surface of both caps. The installation of the egg chamber began by placing an 18-inch diameter barrel over the artificial redd and 8-inch placement pipe. The purpose of the barrel was to minimize the flow of water through the egg chamber during the process of adding the eggs. The egg chamber with a perforated rubber cap fastened on the bottom end with a hose clamp was set vertically within the river water inside of the 18-inch barrel. Then, a 1.5-inch layer of "pea" gravel was placed on the bottom of the chamber to ensure (1) that the eggs did not come in contact with the end cap and (2) that intragravel flows in the vicinity of the eggs were not impeded by the end cap. A 4-inch diameter rock and several other 1- to 2-inch diameter rocks were then placed in the bottom of the incubation chamber over the pea gravel to simulate the "centrum" rock commonly found in natural Chinook salmon redds. Then one cloth bag containing Chinook salmon eggs was opened over the centrum rocks to release the eggs into the chamber (Figure 8). After the eggs had settled below the centrum rocks, 12 inches of cleaned gravel from each study site were then slowly added to the chamber and a perforated rubber cap was fastened to the top with a hose clamp. This left a 3.5-inch high area at the top of the chamber for the emerged alevins. The egg chamber was then inserted vertically into the 8-inch diameter holding pipe and held in place while the 8-inch holding pipe was pulled from the gravel bed. To facilitate removing the 8-inch holding pipe with minimal disturbance to the incubation chamber, the holding pipe had thin, smooth walls and an attached rope handle. A 3-foot by 2-foot re-bar grate was placed over each redd upstream of the incubation chamber to minimize the potential for spawning salmon to disturb the egg chambers.

Egg Chamber Inspection

After allowing 105 to 106 days for the eggs to hatch and the alevins to emerge, water quality measurements were taken in the artificial redds and then the egg chambers were excavated. The chamber's contents were spilled onto vinyl tarps and the live fry and dead alevins were collected. The chambers contents were divided into upper, middle, and lower sections to help assess emergence success. The substrate within the chamber excluding the added pea gravel was saved for particle size sieve analysis in the laboratory. Fork lengths of all fry were measured immediately. The dead eggs were too decayed to count.

Fall 2005 Study

During fall 2005, KDH repeated the egg survival studies at the same sites that were studied in fall 2004 and four additional sites: DFG2-right, DFG2-left, DFG1-side channel, and Riffle R59, which was another KFGRP control site. The U.S. Bureau of Reclamation added two different gravel sizes to DFG2-right and DFG2-left that were cleaned with screens intermediate to the sizes tested in the fall 2004 studies. In addition, the DFG1-side channel site was intended to evaluate the interaction between gravel size and streamflow. However, flood control releases up to about 6,000 cfs in January 2006 displaced or disturbed artificial redds, incubation chambers, and water quality monitoring devices. Therefore, data from 2005-06 field season was not included in analysis and is presented only as raw data in Appendix 5.

Figure 8. Chinook salmon eggs settled to the bottom of the egg incubation chamber below the "centrum" rocks.

WATER QUALITY MEASUREMENTS

Intragravel water quality measurements were made from the undisturbed gravel beds using standpipes driven into the undisturbed streambed to a depth of 12 inches on September 20, 21, and 27, 2004 and on a bi-weekly interval from the mini-standpipes buried adjacent to the egg incubation chambers from the time that they were constructed (e.g., November 12, 2004) until the time that they were excavated (e.g., February 25, 2005). Measurements included D.O. (mg/l), water temperature, turbidity (JTU), and apparent velocity (cm/hr). Permeability measurements at the artificial redds were taken immediately after the redd had been constructed and immediately before the egg chamber was excavated. Measurements were made with the same methods used by CMC during the initial KFGRP studies as described below.

Mini-Standpipe Design and Sample Collection

Mini-standpipes were 1/4-inch outside diameter copper tubes, each with one end of the tube pinched nearly closed and eight 0.04-inch diameter holes punched in the tube near the closed end. The copper tube was fitted through a hole in the bottom of the well screen (Figure 4) to help hold the mini-standpipe in place and to standardize the placement of the apparent velocity flow meter sensor in the well screen. The other end of the copper tubing was attached to a clear polyvinyl chloride (PVC) flexible tube that extended to the surface of the water. The PVC tubing was 1/4-inch inside diameter and had a wall thickness of 1/16 inch. The water samples used to measure intragravel D.O. were collected with a 50-ml polypropylene syringe (Henke-

Sass Wolf GimbH, Germany) fitted with a six-inch long, 1/8-inch inside diameter polypropylene tube and a tapered connector that provided an airtight seal between the mini-standpipe's tubing and the syringe's tubing. Water samples were collected by first slowly withdrawing 50-ml of water, the approximate volume of water in the mini-standpipe=s tubing, and then using it to rinse the sample bottle. Then a 60-ml sample was slowly withdrawn and injected into a LaMotte sample bottle.

Dissolved oxygen concentration
Intragravel D.O. was measured using a LaMotte test kit, model EDO/AG-30. The LaMotte test uses the azide modification of the Winkler Method and a LaMotte Direct Reading Titrator for the final titration. The kit measures D.O. concentration in 0.1 parts per million (ppm) increments. Kit reagents were replaced for each survey. Immediately after the samples were collected at a site, they were fixed and placed in an ice chest. They were analyzed at room temperature within 10 hours after collection.

A surface D.O. sample was collected at each site at the same time the intragravel samples were collected, except during January 2005. The percent saturation of dissolved oxygen for the intragravel samples was computed by dividing the D.O. concentration of the intragravel sample by the D.O. concentration of the surface sample. D.O. is presented in parts per million (ppm) for all dates.

Substrate Permeability
Streambed permeability was measured at nine locations in undisturbed gravels at each of the KFGRP study sites between September 20 and October 31, 2004. Additional measurements were made in the cleaned gravels of the artificial redds within the egg survival study sites immediately after the egg chambers had been buried and immediately before the chambers were excavated.

Substrate permeability depends on the composition and degree of packing of the gravel and the viscosity of the water (as related to water temperature) and reflects Athe ease with which water can pass through it@ (Pollard 1955). Measurements were made with standpipes that were similar to the Terhune Mark IV permeability standpipe (Terhune 1958). The standpipes were 4.5 feet long and made of 1.12-inch (28 mm) inside diameter schedule-40 stainless steel pipe with a 3-inch long solid stainless steel driving tip at one end. Above the driving tip, there was a three-inch long cavity to store sand that entered the pipe during sampling. Immediately above the cavity, there was a three-inch long band of perforations around the standpipe. The perforations were 0.12 inch (3-mm) diameter holes, spaced 0.75 inches apart in columns of four holes. A 0.08-inch (2-mm) wide groove was cut about 0.08 inches deep along each of the columns to prevent sand grains from plugging the holes. There was a total of 12 rows of holes and every other column was offset by 0.375 inches to stagger the holes. A one-inch thick driving head was inserted into the standpipe when driving it into the streambed. The standpipe was marked with a band of red plastic tape 19.5 inches from the driving tip. When the standpipe was driven into streambed to the red tape, the middle of the band of perforations was 12 inches below the surface of the substrate.

Permeability measurements were made with a homemade pumping device that employed a 12-volt DC battery and a 35 psi diaphragm vacuum pump (*Thomas*, model #107CDC20-975C) to draw water into a clear cylindrical vacuum chamber, 3.56 inches in diameter and 20 inches long. The device was mounted on a backpack frame. Two 3/8- inch polypropylene hoses were used, one to connect the pump to the vacuum chamber and the other to draw water from the standpipe into the vacuum chamber. A 1/4-inch inside diameter plastic tube and a fiberglass tape with gradations in centimeters was attached to the side of the vacuum chamber to measure the change in height (i.e., volume) of the water drawn into the vacuum chamber. For each one-centimeter change in water height in the chamber, 64.7 ml were drawn into the chamber.

To measure permeability, the pump was switched on and the hose was slowly lowered into the standpipe until a slurping noise was heard indicating that there was contact with the water. A one-inch spacer was then placed on top of the standpipe and a clamp was attached immediately above the spacer to the side of the hose without constricting it. The pump was then switched off, the spacer removed, and the hose lowered until the clamp rested on top of the standpipe. This placed the end of the hose one inch below the water's surface in the standpipe. Then, the pump was switched on and after the water level in the vacuum chamber reached the zero mark, the stopwatch was activated. Usually after 1,294 ml had been collected, the stopwatch was turned off and the duration and volume were recorded. When pumping rates were extremely slow, pumping was continued for at least 40 seconds and then the volume of water pumped and the exact duration were recorded. Water temperature was measured in the standpipe with an *Extech* electronic thermometer to the nearest 0.1 degrees Celsius to determine a viscosity correction factor.

Permeability was then interpolated from an empirical permeability versus a corrected inflow rate calibration table provided by McBain and Trush (CMC 2002b). The calibration table provides conversions up to 110.9 ml/sec for field inflow rates whereas higher rates were measured at the restoration sites and in redds. Conversions were made for readings that exceeded 110.9 ml/sec by increasing the permeability by 500 cm/hr for each 0.1 ml/sec increase in the field inflow rate beyond 110.9 ml/sec. For example, a field inflow rate of 111.0 ml/sec was converted to a permeability of 105,000 cm/hr. After the field inflow rates were converted to a permeability value, the permeability value was standardized to a temperature of 10 degrees Celsius by the viscosity correction factor presented in Barnard and McBain (1994).

Apparent velocity

Apparent velocity was measured using a *KVA* model 40L Geoflo Groundwater Flowmeter inserted 12-inches into the substrate of each riffle in a slotted well pipe (described in the artificial redd section above). The meter measures the direction and rate of intragravel flow by measuring the displacement rate of a 500° F pulse of heat emitted from the center of the device toward four equally spaced pairs of thermistors as described in CMC (2002b). Measurements were taken from within a slotted well screen which permitted roughly 40% of unimpaired flow to pass through it. Measurement and calibration methods used by KDH are described in detail in CMC 2002c. The meter was calibrated under laboratory conditions in restoration gravels cleaned with a 1/4-inch screen (from Riffle R19) up to a flow of 35 feet/hour (10.7 meters/hour), which was greater than the measurements observed during the field studies.

Turbidity
Turbidity was measured at all artificial egg incubation chambers on a roughly biweekly basis from November 6, 2004 through February 25, 2005. Intragravel turbidity was measured using 60-ml samples collected from the mini-standpipe and a LaMotte test kit.

Water Temperature
Onset StowAway TidbiT thermographs attached to the bottom of each apparent velocity well screen were used to measure intragravel water temperature in the egg chambers. Two thermographs were placed along side each egg chamber and in surface flows for each study reach. Thermograph measurements were made at 30-minute intervals throughout the egg incubation period. Surface water temperature measurements were also made with a hand-held Engel digital thermometer when other water quality measurements were made on a bi-weekly basis.

The magnitude of fluctuation of intragravel water temperatures relative to surface water temperatures was used as an indicator of the rate of downwelling of surface flow into the streambed (CMC2002c). High downwelling rates and the resulting high D.O. levels (Wu 2000) correspond to sites where the magnitude of fluctuation of intragravel water temperatures matches those of surface water. However, sites experiencing upwelling of poorly oxygenated hyporheic groundwater typically have relatively high and stable intragravel water temperatures compared to surface water temperatures (CMC 2002c).

NATURAL REDD EXCAVATION

In order to examine the effect of redd superimposition on egg survival and the entombment of alevins, 12 superimposed and 10 non-superimposed natural Chinook salmon redds were excavated from KFGRP restoration gravel natural gravel at riffles R12B, R14, R14A, R15, R19, R19A, R20, R57, and R58. To avoid damage to viable salmon fry, the redds were excavated in March 2005, approximately 120 days after the redds had been constructed. The redds were excavated with hand-held shovels and then allowed to fall from the water's surface. The flow carried the fry and eggs into large dip nets with 1/8-inch mesh held immediately downstream from the redd. Estimates were made of the number of live fry that escaped the dip nets. The number of live fry, dead alevins, and eggs was recorded for comparison between the gravel types and between superimposed and non-superimposed redds using two-sample *t*-tests.

SUBSTRATE ANALYSIS

In the spring of 2005 and 2006, bulk samples were taken from within and directly in front of each of the artificial egg chambers. Samples from within the chamber were collected after egg survival was assessed; samples from in front of chambers were collected just before pulling chambers for egg survival analysis. To collect samples from in front of incubation chambers, an 18-gauge stainless steel cylindrical bulk sampler was used that was 18 inches in diameter, 42 inches high, had two handles, and a serrated bottom (CMC 2001). It was pushed into the streambed to a depth up to 12 inches. A shovel with the edge of its blade modified to fit tightly against the inside of the bulk sampler was used to excavate the substrate. The samples analyzed from within the egg chambers excluded the "pea" gravel and the "centrum rocks". A mean of 10.4 kilograms was collected in front of each egg chamber whereas a mean of 9.1 kilograms was collected from within each chamber. The substrate samples were dried completely and analyzed by weight using a *Gilson* Sieve Tester (shaker), and *Gilson* USA Standard Testing Sieves. Samples were sieved into ten distinct size classes (number 20, 18, 10, 5 and five sieves as well as 3/8-inch, 5/8-inch, 1.25-inch, and 2.5-inch screens). The particles collected in the 5/8-inch sieve at Riffle DFG1 were measured with a hand held caliper. Bulk substrate samples were also collected from naturally occurring Chinook salmon redds during redd excavation at riffles R12A, R12B, R14, R14A, R15, R19, R19A, R20, R57, and R58.

STATISTICAL ANALYSIS

All statistical analysis was completed using the software program Statistix, Version 8.0 and 9.0 and the Excel add-in pop-tools (for ANOVA). Charts, graphs and tables were constructed in Microsoft Office program Excel (2003).

RESULTS

The results of the spawning surveys, intragravel water quality measurements, streambed contour mapping, and egg survival studies conducted in fall 2004 are presented below relative to the seven hypotheses listed in the Introduction. The results of the fall 2005 studies that were not successful due to flood control releases are presented in Appendix 5.

DISTRIBUTION OF SALMON SPAWNING

A total of 353 redds was observed where gravel had been placed at the 18 project riffles and 855 redds were observed at the 10 control sites and in natural gravel adjacent to the gravel placement areas in fall 2004 (Table 1). The escapement estimate was 4,404 adult Chinook salmon through December 31, 2004 as determined by the Cramer Fish Sciences counting weir at Ripon. This is slightly more than half of the escapement estimate of 8,490 adult salmon for fall 2000 based on the Department of Fish and Game carcass survey (GrandTab, March 2008[1]). In fall 2000, a total of 2,008 redds was observed at the same 28 study sites.

Table 1. The number of fall-run Chinook salmon redds inside and outside of the areas where restoration gravel was placed in August 1999, spawning area, density of redds, and distance downstream from Goodwin Dam for the 28 KFGRP study riffles surveyed between November 5 and 27, 2004.

Site	Number of Redds		Spawning Area (square-yards)		Redds/yd^2		Miles Below Goodwin Dam
	Inside	Outside	Inside	Outside	Inside	Outside	
TMA	49	7	256	118	0.19	0.06	1.7
TM1	--	70	--	347	--	0.20	1.9
R1	31	27	282	70	0.11	0.39	4.0
R2	--	60	--	352	--	0.17	4.0
R5	14	5	123	38	0.11	0.13	4.6
R10	--	31	--	516	--	0.06	5.0
R12	--	19	--	138	--	0.14	5.2
R12A	11	13	114	123	0.10	0.11	5.7
R12B	28	8	164	20	0.17	0.40	5.7
R13	24	--	341	0	0.07	--	5.8
R14	42	12	436	119	0.10	0.10	5.9
R14A	13	20	137	495	0.09	0.04	5.9
R15	18	6	175	26	0.10	0.23	6.0
R16	14	3	154	13	0.09	0.23	6.0
R19	30	15	316	419	0.09	0.04	6.4
R19A	24	--	193	0	0.12	--	6.4
R20	--	67	--	1021	--	0.07	6.7
R26	--	10	--	143	--	0.07	7.1

[1] The California Department of Fish and Game escapement estimates are published by the Sacramento office. The GrandTab file that contains all of the estimates is available online at http://www.delta.dfg.ca.gov/afrp/

Site	Number of Redds		Spawning Area (square-yards)		Redds/yd^2		Miles Below Goodwin Dam
	Inside	Outside	Inside	Outside	Inside	Outside	
R27	--	9	--	217	--	0.04	7.7
R28A	9	0	111	12	0.08	0.00	8.3
R29	8	4	107	96	0.07	0.04	8.8
R43	11	9	143	277	0.08	0.03	11.6
R44	--	4	--	431	--	0.01	11.7
R57	7	--	191	0	0.04	--	13.9
R58	12	2	392	13	0.03	0.16	14.0
R59	--	3	--	260	--	0.01	14.1
R76	--	4	--	126	--	0.03	18.2
R78	8	0	291	190	0.03	0.00	18.3

As occurred in fall 1998 (CMC 2001), fall 1999 (CMC 2002b), and fall 2000 (2002c), redd densities were highest at the upstream sites and they declined in a downstream direction (Figure 9). To test hypotheses that gravel source and screen size affected redd density, it was necessary to use two-tailed *F*-tests to compare the residual variances, slope, and elevations of the regressions of redd density versus distance downstream between the different gravel mixtures shown in Figure 9 (Snedecor and Cochran 1989, pages 390-393). The *F*-test requires that the variance of the regressions should not be significantly different before testing the slope and elevation of the regressions. Although, there were no significant differences between the regression variances for any comparisons of the different gravel types, none of the slopes or elevations of the compared regressions were statistically different (Table 2).

Table 2. The results of two-tailed F-tests comparing the redd densities versus distance downstream for the different gravel mixtures and control sites.

	Probability Level (degrees of freedom)		
Gravel Comparison	Equality of Variances	Comparison of Slopes	Comparison of Elevations
1/4-inch screen vs. control gravels	0.180 (4, 8)	0.923 (1, 12)	0.665 (1, 13)
3/8-inch screen vs. control gravels	0.259 (4, 8)	0.499 (1, 12)	0.682 (1, 13)
1/4-inch screen vs. 3/8-inch screen	0.371 (4, 4)	0.819 (1,8)	0.810 (1, 9)
Stanislaus gravel vs. Tuolumne gravel	0.184 (4, 4)	0.106 (1, 8)	0.333 (1, 9)

The primary change that occurred between fall 2000 and fall 2004 is that the sites with the Stanislaus River rock degraded to the point that spawner use at the restoration sites was equal to the spawner use at the control sites. The gradual reduction in redd density was probably due to the gradual armoring of the bed's surface (loss of smaller particles) as well as fine sediment intrusion that compacted the beds and therefore made it more difficult for the salmon to construct their redds. On the other hand, spawner use remained the same at the restoration sites that were constructed with Tuolumne River rock and as a result, eventually all sites had about the same redd densities. Therefore, Hypothesis 1: *Chinook salmon spawners prefer to use native Stanislaus River rock compared to imported rock from the Tuolumne River* was true for only the first few years after gravel placement (CMC 2002b, 2002c). Hypothesis 2: *Chinook salmon spawners prefer to use gravel cleaned with a 1/4-inch screen and a 5-inch grizzly compared to gravel cleaned with a 3/8-inch and a 5-inch grizzly* was rejected based on the results of the fall 1999 (CMC 2002b), fall 2000 (CMC 2002c), and fall 2004 studies.

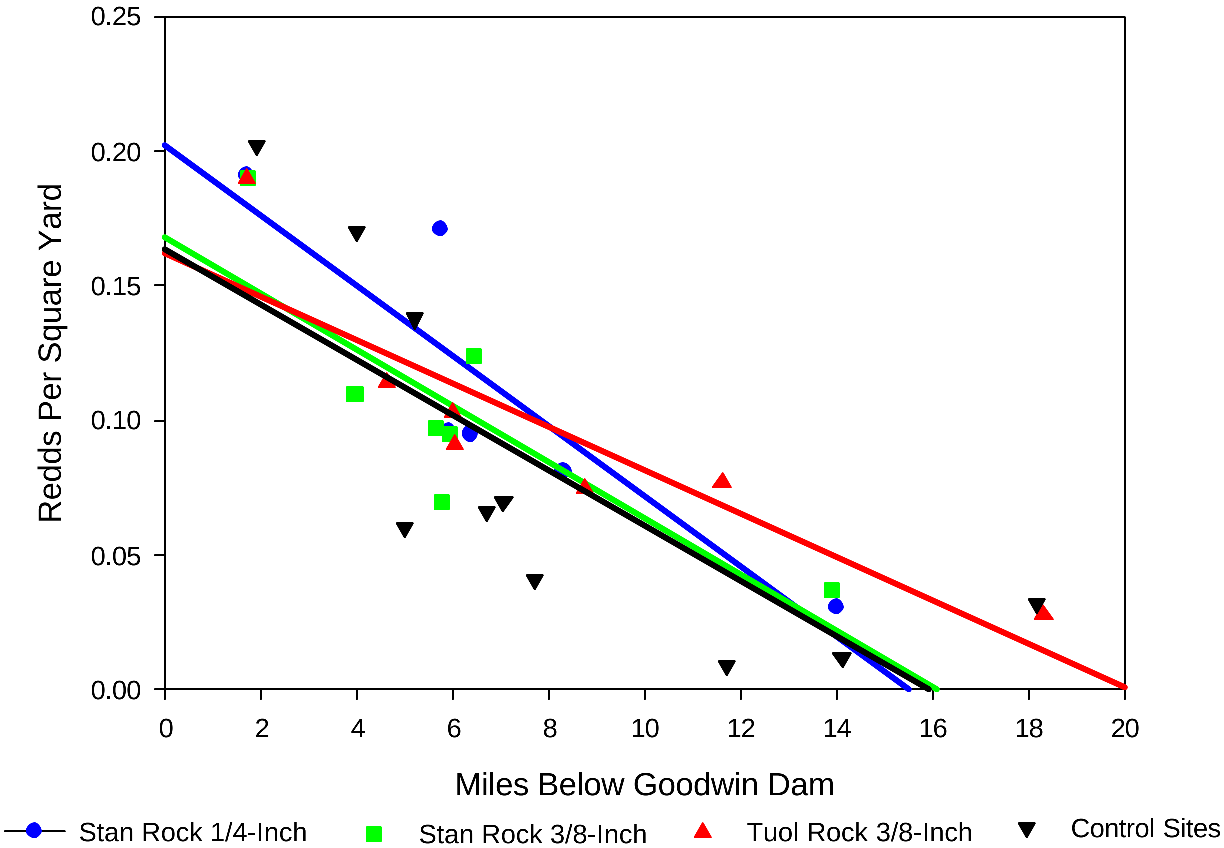


Figure 9. Chinook salmon redd densities at project sites that received three different mixtures of gravel: (1) Stanislaus River rock cleaned with a 1/4-inch screen, (2) Stanislaus River rock cleaned with a 3/8-inch screen, and (3) Tuolumne River rock cleaned with a 3/8-inch screen, and 10 control sites relative to the distance below Goodwin Dam in the Stanislaus River in fall 2004. Regression models are shown as lines. The regression models for the Stanislaus River 3/8-inch screened rock and the Tuolumne River rock were adjusted by assuming that redd densities at the uppermost Two-Mile Bar sites (TMA and TM1) would be similar to the observed Stanislaus River 1/4-inch screened rock and the control site, which were nearly identical at about 0.2 redds/square-yard. The adjustment improved the comparability of the regression models for this graphic. No adjustment was made for the statistical analysis described above.

INTRAGRAVEL WATER QUALITY

The third hypothesis: *Adding gravel without fines to the streambed increases intragravel D.O. concentrations and intragravel flow rates compared to those at the control riffles* was tested by comparing streambed permeability in undisturbed gravel in restored project riffles with natural control riffles in fall 2004. The fall 2004 results, which represented conditions five years after the project sites had been constructed, were also compared to the fall 1999 and 2000 results. The lack of measurements of D.O. concentration at all of the 28 KFGRP study sites precluded an analysis of intragravel D.O. concentration for the Phase II studies.

In September 2004, the streambed permeability was significantly higher in the undisturbed gravels in the KFGRP project riffles that contained Stanislaus River rock cleaned with 1/4-inch and 3/8-inch screens compared to the ten KFGRP control sites based on *t*-tests (Table 3). However, there was no difference between the streambed permeability estimates at the KFGRP project riffles with Tuolumne River rock cleaned with a 3/8-inch screen and the ten KFGRP control sites (Table 3). The results of the *t*-tests are presented in Table 4.

Table 3. Mean permeability estimates (cm/hr) and sample size (N) for measurements taken at a depth of 12 inches in undisturbed gravels at the restoration and control sites in fall 2004, 2000, and 1999. At the restoration sites, measurements were taken where the restoration gravel was at least 18 inches deep.

Gravel type	Fall 2004 Mean Permeability	N	Fall 2000 Mean Permeability	N	Fall 1999 Mean Permeability	N
Stanislaus River Rock 1/4-inch Screen	29,458	54	44,971	13	150,990	8
Stanislaus River Rock 3/8-inch Screen	31,591	52	37,493	20	171,436	20
Tuolumne River Rock 3/8-inch Screen	13,006	54	45,454	15	204,827	6
Natural Control Riffles	13,885	86	5,363	31	3,477	21

Table 4. The test for equality of variances and the probability that the differences between the mean permeability estimates for fall 2004 in Table 3 are significant based on *t*-tests.

Comparison	Test for Equality of Variances (degrees of freedom)	Probability Differences Are Significant
Stanislaus River Rock 1/4-inch Screen versus Control Riffle	0.0008 (53, 85)	0.0116
Stanislaus River Rock 3/8-inch Screen versus Control Riffle	0.0004 (51, 85)	0.0058
Tuolumne River Rock 3/8-inch Screen versus Control Riffle	0.1163 (53, 85)	0.8413

The relatively low permeability estimates for the Tuolumne River Rock may be the result of heavy fine sediment loading near four of the sites that received Tuolumne River rock (R15, R16, R29, and R78) and only one of the sites that received Stanislaus River rock (R14A, Figure 10). The permeabilities were particularly low at three project sites that were adjacent to the Ohe Sand and Gravel quarry (R14A, R15, and R16), where storm runoff was observed to have flushed fine sediments into the river and onto these sites in 1999. The permeabilities were also low at Riffle 78, which is downstream of the City of Oakdale where a large amount of fine sediment is stored in the riverbed. Riffles R5 and R43, which also received Tuolumne River rock, had permeabilities that were similar to the estimates for the sites that received Stanislaus River rock and so it is unlikely that the Tuolumne River particle size distribution was a factor in the relatively rapid decline of the permeability levels.

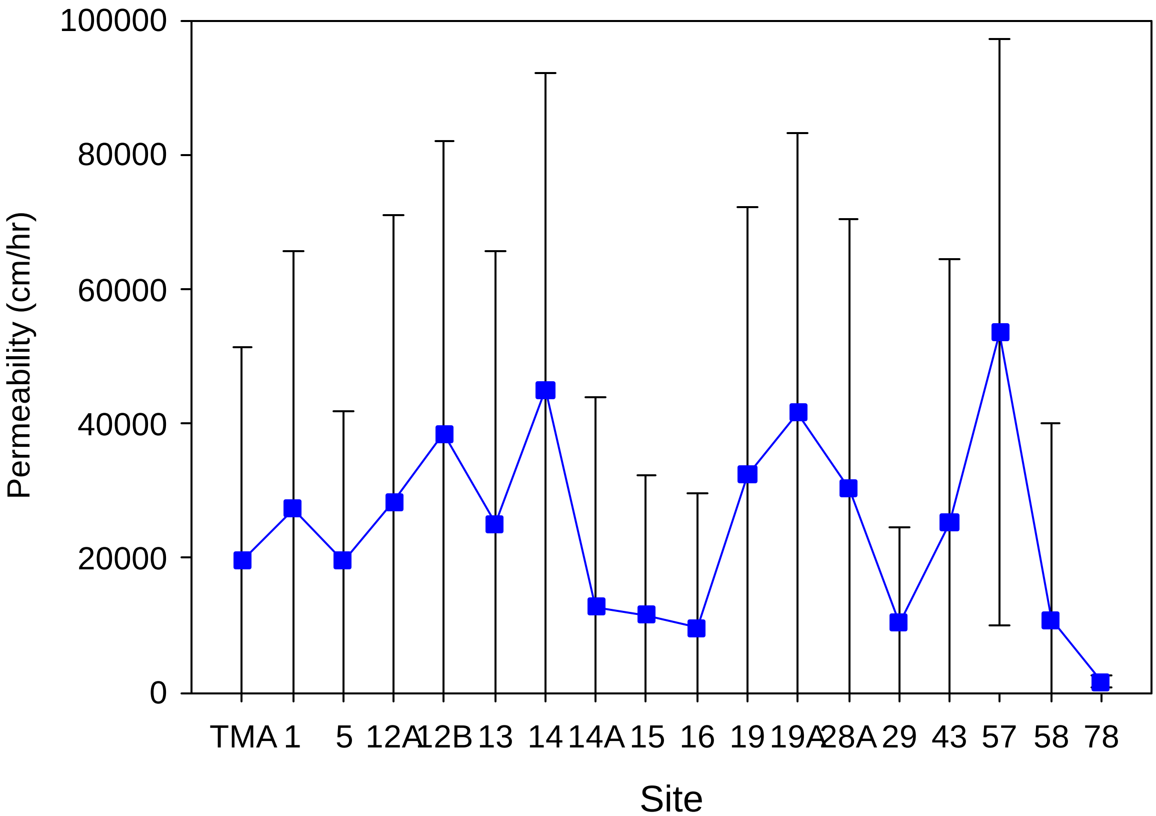


Figure 10. Mean permeability and standard deviation (error bars) at a depth of 12 inches in undisturbed gravel within KFGRP restoration sites in the Stanislaus River in September 2004. Sites are arranged along the x-axis from the upstream most site (TMA) to the downstream most site (R78).

EGG SURVIVAL TO EMERGENCE

There were two elements of the egg survival to emergence studies. One evaluated the effect of screening fine sediment from restoration gravels compared to silty natural gravels and the other evaluated the effects of turbid storm runoff on egg survival. The first element also investigated whether the size of the screen mesh used to clean the gravel affected egg survival rates.

Gravel Size

The fourth hypothesis, *Restoring Riffle Habitat With Clean Gravel Will Increase Egg Survival And The Size Of Fry Compared To Control Riffles*, was tested by comparing egg survival in three different sizes of restoration gravel: gravel cleaned with a 1/4-inch screen at Riffle R19, a 3/8-inch screen at Riffle R19A, and a 1-inch screen at Riffle DFG1 relative to egg survival rates at the control site R20, which was highly used by spawners and had a mean streambed permeability of 19,832 cm/hr (N = 9) in undisturbed gravels, which was relatively high compared to the other control sites (Table 3). The mean particle size distributions of gravel samples taken from the five artificial redds at each site are shown in Figure 11.

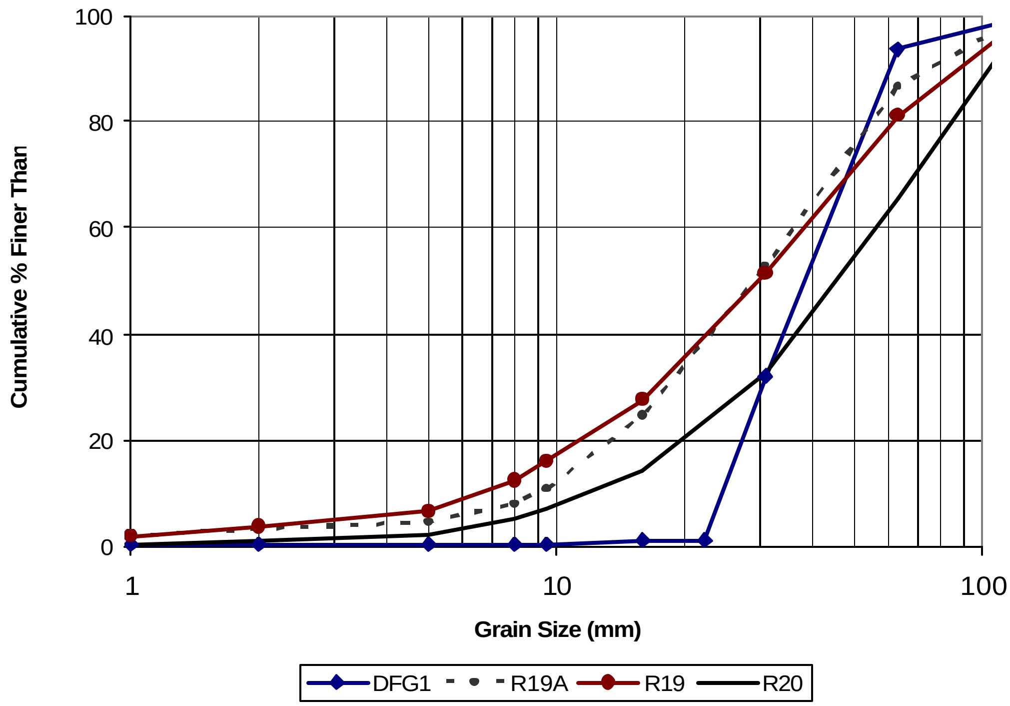


Figure 11. Mean cumulative particle size distribution curves for substrate bulk samples taken from the five artificial redds taken at riffles DFG1 (1-inch screen), R19A (3/8-inch screen), R19 (1/4-inch screen) and R20 (natural control site) in February 2005 immediately after pulling the egg incubation chambers. The curve for Riffle DFG1 includes a measurement of the particles finer than 22.2 cm (7/8 inches) that was determined by measuring the particles in the 16 mm screen with a hand-held caliper; none of the particles in the 16 mm screen were smaller than 22.2 cm in diameter.

Photos of the contents of an egg chamber from Riffle R19 (1/4-inch screen) and DFG 1 (1-inch screen) are shown in Figures 12 and 13, respectively. It was common that fry were vertically distributed throughout the chambers (Figure 12) and there were no accumulations of fines that would have caused their entombment. Therefore, it was assumed that fry in the lower sections of the chambers were simply looking to escape and were not entombed.

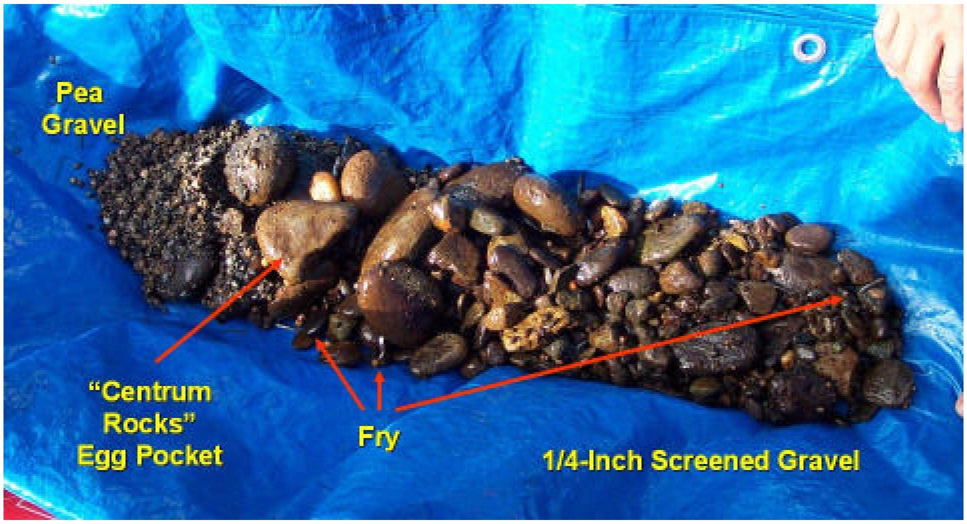


Figure 12. Contents of an egg chamber at Riffle R19 immediately after it was pulled from the streambed. The chamber contents were spilled onto vinyl tarps to maintain the vertical integrity of the contents to the extent possible. The photo identifies the "pea gravel" placed on the bottom of the chamber, the "centrum rocks" placed on top of the pea gravel where the eggs were held, and the 12 inches of 1/4-inch screened gravel from Riffle R19 that was placed over the eggs.

Figure 13. Contents of an egg chamber at Riffle DFG1 immediately after it was pulled from the streambed.

The mean egg survival rates were about 70% at each of the KFGRP sites (R19 and R19A) and the control site (R20) at Lovers Leap; whereas the mean egg survival rate was near zero at Riffle DFG1 in Goodwin Canyon which had gravel cleaned with a 1-inch screen (Table 5). Based on two sample t-tests, there were no significant differences between the mean survival rates or the mean fork lengths at the KFGRP sites with gravel cleaned with 1/4-inch and 3/8-inch screens and the control site (Table 6). The difference in the mean egg survival rate between DFG 1 and the control site R20 was highly significant (Table 6).

Table 5. Dates that eggs were planted in chambers and removed from the streambed, the survival rate of about 2,000 eggs from the same female held at the hatchery, the fork length of the female, the approximate number of eggs placed in each chamber based on the count of one of 15 samples measured in a 1/3-cup container, the mean fork length of the fry on the date the chamber was removed from the streambed, and the egg survival rates for five chambers planted at each of three different restoration gravel mixtures and a control site (R2) in November 2004.

KFGRP Site	R19	R19A	DFG1	R20
Planting Date	11/12/2004	11/12/2004	11/8/2004	11/12/2004
Removal Date	2/25/2005	2/25/2005	2/22/2005	2/25/2005
Hatchery Survival Rate	93.87%	93.87%	88.22%	93.87%
Female Fork Length	73 cm	73 cm	81 cm	73 cm
Eggs per Chamber	199	199	220	199
Screen Size	1/4-inch	3/8-inch	1-inch	Natural
Egg Chamber 1	86.36%	78.64%	0.00%	52.27%
Egg Chamber 2	55.00%	76.82%	0.00%	49.09%
Egg Chamber 3	82.73%	83.18%	0.00%	88.18%
Egg Chamber 4	86.82%	82.27%	4.55%	85.45%
Egg Chamber 5	53.18%	41.82%	0.00%	75.45%
Mean Survival	72.82%	72.55%	0.91%	70.09%
Mean Fork Length (mm)	36.10	36.31	34.40	36.16

Table 6. Results of *t*-tests comparing egg survival and fry size between three different restoration gravel mixtures and a natural control site in the Stanislaus River. Riffles R19, R19A, and DFG 1 received restoration gravels cleaned with a 1/4-inch, 3/8-inch, and 1-inch screens, respectively.

Comparison	Variable	Test for Equality of Variances (degrees of freedom)	Probability Differences Are Significant
R19 ? R20	Egg Survival	0.4498 (4, 4)	0.8144
R19A ? R20	Egg Survival	0.4580 (4, 4)	0.8334
DFG1 ? R20	Egg Survival	0.0004 (4, 4)	0.0010
R19 ? R20	Mean Fork Length	0.2416 (4, 4)	0.2362
R19A ? R20	Mean Fork Length	0.0840 (4, 4)	0.1562
DFG1 ? R20	Mean Fork Length	Insufficient Data	

Turbid Storm Runoff In Downstream Reaches

The sixth hypothesis, S*urvival Is Significantly Lower For Eggs Exposed To Turbid Storm Runoff,* was tested by comparing egg survival rates between upstream sites (Lovers Leap) and downstream sites (Valley Oak) and by comparing early egg plantings (November 8 and 12, 2004) with late egg plantings (December 2, 2004) at the same sites (Tables 7 and 8). Turbidity during storm runoff had been higher in the downstream reaches and during the latter part of the incubation season during the fall 1999 and 2000 studies. It was assumed that high intragravel turbidity would coat salmon eggs with clay-sized particles and potentially suffocate the eggs or stunt egg development (Reiser and White 1988, CMC 2001); however, alevins would not be affected by turbidity compared to eggs because the alevins have gills which are much more efficient for absorbing oxygen compared to the egg's membrane. Therefore, the effect of turbidity was assumed to be most pronounced during the 45-day period of egg incubation.

During the 2004-2005 season, the first major storm runoff occurred from December 21 through 28, 2004 when the mean daily flow at the Orange Blossom Bridge gage increased from the base flow of about 300 cfs to a peak of 1,973 cfs. Thereafter, only relatively small storms occurred in January 2005. Because the storms occurred relatively early during the incubation season in 2004, the turbid storm runoff from the first large storm would have affected both the eggs planted in early November and those planted in early December, because both sets of eggs had not yet hatched or developed gills when the storm event occurred.

Measuring intragravel turbidity was difficult because the clay-sized particles tended to settle out in the substrate, the mini-standpipe, and its tubing. This resulted in an initial pulse of high turbidity that gradually declined as the water sample was drawn from the mini-standpipe. The water sample from the mini-standpipe that was used to measure turbidity was taken after 120 ml had been withdrawn for the dissolved oxygen sample. Therefore, the measurements reported below should be considered to be an index of the amount of clay-sized particles contained in the egg chamber.

The mean intragravel turbidity index on November 16 and 17, which was before any storm runoff occurred, was 7.83 JTU (N=30) whereas it increased to 14.17 JTU on January 17 and 18, 2005 after most of the storm runoff had occurred; the means were not significantly different ($p = 0.11$) based on a paired *t*-test. The mean intragravel turbidity index increased from 2.5 JTU at DFG1, to a mean of 11.7 JTU in Lovers Leap (R19, R19A, and R20), up to a mean of 18.9 JTU at the Valley Oak sites (R57 and R58) in mid-January following the storms (Figure 14).

The mean egg survival rate was 74.7% for the 15 egg chambers planted at Riffles R19 and R19A in the upstream Lovers Leap reach and 32.6% for the 15 egg chambers planted at Riffles R57 and R58 in the downstream Valley Oak reach for the November and December plantings combined (Table 7). The means were significantly different ($p = 0.0000$) based on a two sample *t*-test for comparisons with unequal variances (Table 8). Comparisons of the means for the November and December plantings at R19A and R57 were not significantly different based on two sample *t*-tests (Table 8).

The means of the fork lengths of the fry in the Lovers Leap and the Valley Oak egg chambers were 34.3 mm and 34.4 mm, respectively (Table 7). The differences were not significant based on a two sample *t*-test (Table 8).

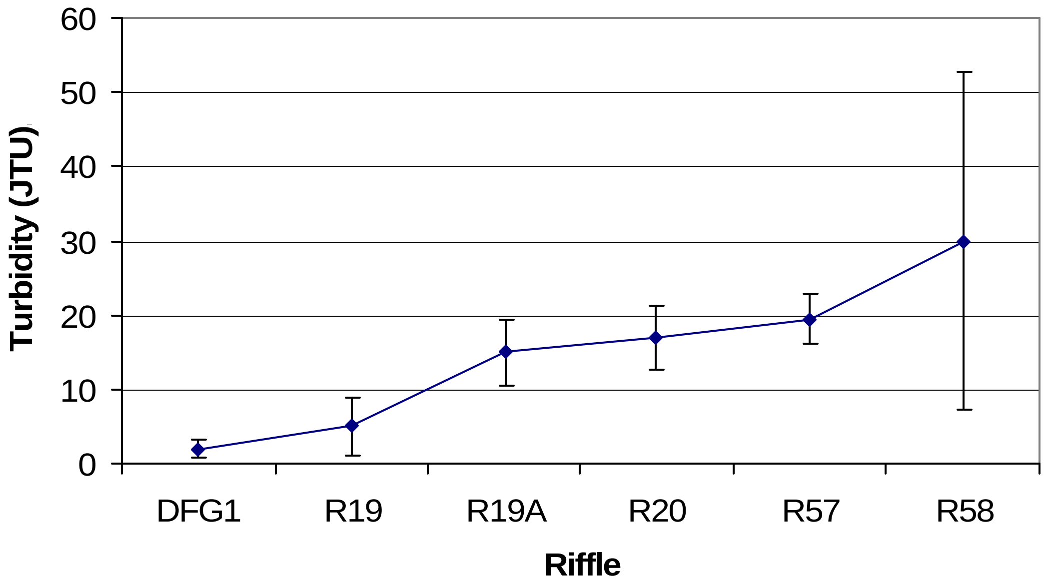


Figure 14. Mean intragravel turbidity levels (JTU) and standard deviation (error bars) at egg incubation study riffles in Goodwin Canyon (DFG1), Lovers Leap (R19, R19A, and R20), and Valley Oak (R57 and R58) on January 17 and 18, 2005. Riffle R20 was the unrestored riffled used as the control for this study.

Table 7. Dates that eggs were planted in chambers and removed from the streambed, the survival rate of about 2,000 eggs from the same female held at the hatchery, the fork length of the female, the approximate number of eggs placed in each chamber based on the count of one of 16 samples measured in a 1/3-cup container, the mean fork length of the fry on the date the chamber was removed from the streambed, and the egg survival rates for five chambers planted at each of two different restoration gravel mixtures in the upstream Lovers Leap Reach (R19 and R19A) and the downstream Valley Oak reach (R57 and R58) in November and December 2004.

KFGRP Site	R19	R19A	R19A	R57	R58	R57
River Mile	6.37	6.44	6.44	13.9	14.0	13.9
Planting Date	11/12/2004	11/12/2004	12/02/2004	11/8/2004	11/8/2004	12/02/2004
Removal Date	2/25/2005	2/25/2005	3/17/2005	2/22/2005	2/22/2005	3/17/2005
Hatchery Survival Rate	93.87%	93.87%	94.88%	88.22%	88.22%	94.88%
Female Fork Length	73 cm	73 cm	83 cm	81 cm	81 cm	83 cm
Eggs per Chamber	199	199	323	220	220	323
Screen Size	1/4-inch	3/8-inch	3/8-inch	3/8-inch	1/4-inch	3/8-inch
Egg Chamber 1	86.36%	78.64%	80.80%	30.91%	16.36%	83.59%
Egg Chamber 2	55.00%	76.82%	82.97%	39.09%	40.00%	16.10%
Egg Chamber 3	82.73%	83.18%	72.14%	33.18%	39.55%	79.57%
Egg Chamber 4	86.82%	82.27%	69.97%	15.91%	31.82%	0.62%
Egg Chamber 5	53.18%	41.82%	88.24%	7.27%	52.27%	3.41%
Mean Survival	72.82%	72.55%	78.82%	25.27%	36.00%	36.66%
Mean Fork Length (mm)	36.10	36.31	32.37	34.84	34.87	32.18%

Table 8. Results of *t*-tests comparing egg survival between the upstream Lovers Leap sites (R19 and R19A) with those at the downstream Valley Oak sites (R57 and R58) for chambers planted on November 8 and 12, 2004 and comparing egg survival between the November 8 and 12, 2004 egg plantings with the December 2, 2004 egg plantings in the Stanislaus River. Riffles R19 and R58 were constructed with restoration gravels cleaned with a 1/4-inch screen and riffles R19A and R57 were constructed with restoration gravels cleaned with a 3/8-inch screen.

Comparison	Variable	Test for Equality of Variances (degrees of freedom)	Probability Differences Are Significant
R19 ? R58 Nov	Egg Survival	0.3108 (4, 4)	0.0052
R19A ? R57 Nov	Egg Survival	0.3039 (4, 4)	0.0013
Lovers Leap ? Valley Oak	Egg Survival	0.0197 (14, 14)	0.0000
R19A Nov ? R19A Dec	Egg Survival	0.0700 (4, 4)	0.4805
R57 Nov ? R57 Dec	Egg Survival	0.0239 (4, 4)	0.5847

Environmental Variables Correlated With Egg Survival

Egg survival was high at all the Lovers Leap sites (R19, R19A, and R20) for the November and December plantings, intermediate at the Valley Oak sites (R57 and R58) for the November planting, highly variable for the Valley Oak site (R57) for the December planting, and near zero at the Goodwin Dam site (DFG1). The most plausible explanation for the near zero egg survival rates observed at the Goodwin Dam site (DFG1) is that the intragravel flow rates were high and the interstitial spaces in the gravel bed were too large, which allowed the newly fertilized eggs to be excessively agitated. The gravel collected from the artificial redds at Riffle DFG1 near Goodwin Dam was cleaned with a 1-inch screen and only 1.7% of the particles were smaller than 7/8 inches (22.2 mm; Figure 15). In comparison, the gravel samples collected from the artificial redds at the Lovers Leap sites had substantially more sediment that was smaller than 5/8 inches (16 mm) in diameter than the Goodwin Dam site (Figure 15).

Screen Size

All of the environmental conditions that affect egg survival were highly suitable at Riffle DFG 1 except for the abnormally large interstitial spaces and high intragravel flow rates. Conditions such as intragravel D.O. concentration (Figure 16), water temperature (Figure 17), turbidity (Figure 18), and the percentage of fines < 2mm (Figure 19) were all highly suitable for the survival of Chinook salmon eggs at Riffle DFG1 and similar to the conditions at the Lovers Leap sites where egg survival was high. The lack of small sediment particles at DFG1 created an abnormally porous streambed with high intragravel flows. The measurements of apparent velocity suggest that there is a threshold of about 20 feet/hour (6.1 meters/hour) above which pre-eyed eggs cannot survive (Figure 20). However, it is unlikely that a flow rate of 20 feet/hour alone would result in nearly total egg mortality because Reiser and White (1988) observed high survival rates for newly fertilized (a.k.a. green) Chinook salmon eggs at apparent velocities up to 50.8 feet/hour (15.5 meters/hour) in laboratory troughs. The primary difference between the KFGRP egg survival study and the Reiser and White (1988) study is that Reiser and White used gravel mixtures that included a substantial percentage of particles smaller than 7/8 inches. It is possible that the DFG1 gravel mixture was abnormally coarse with large interstitial spaces that allowed the eggs to be excessively agitated, unlike more natural gravel mixtures that hold the eggs still.

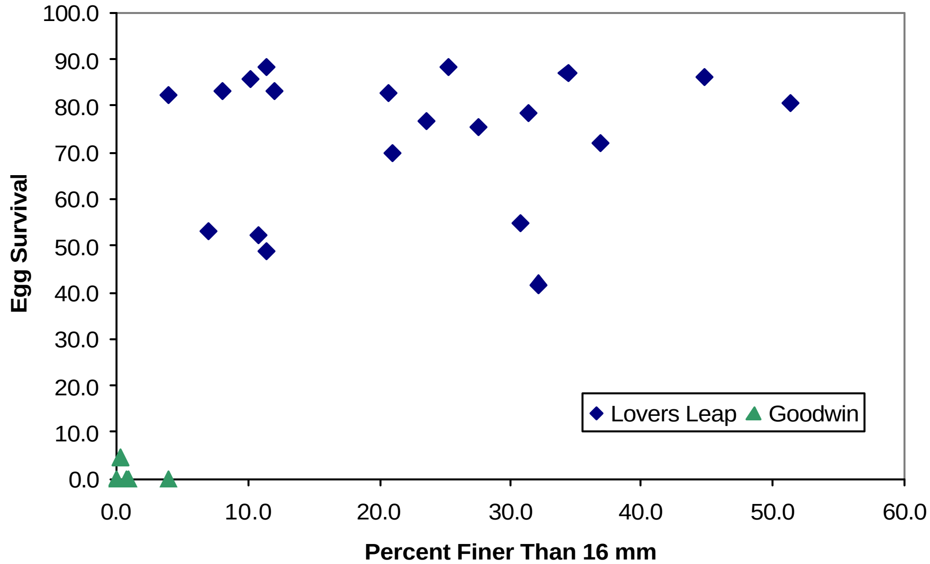


Figure 15. The percent of newly fertilized Chinook salmon eggs that survived relative to percentage of sediment samples from artificial redds that was finer than 16 mm at the Goodwin Dam (DFG1) and Lovers Leap sites (R19, R19A, and R20).

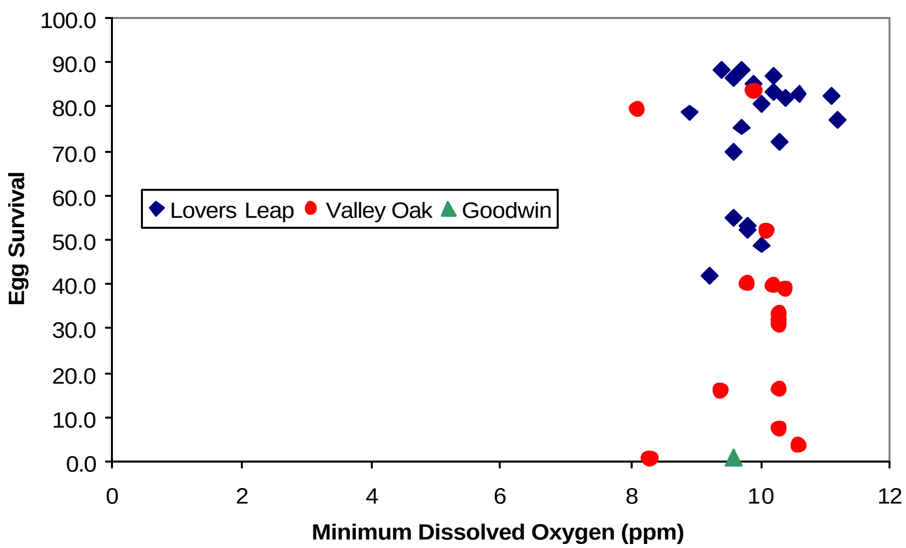


Figure 16. The percent of newly fertilized Chinook salmon eggs that survived relative to the minimum intragravel dissolved oxygen concentration in artificial redds at the Goodwin Dam (DFG1), Lovers Leap (R19, R19A, and R20), and Valley Oak sites (R57 and R58) that occurred before December 21, 2004, which was prior to egg hatching. Other researchers have shown that salmonid egg survival rates were high when dissolved oxygen concentrations were at least 9 ppm (CMC 2002b).

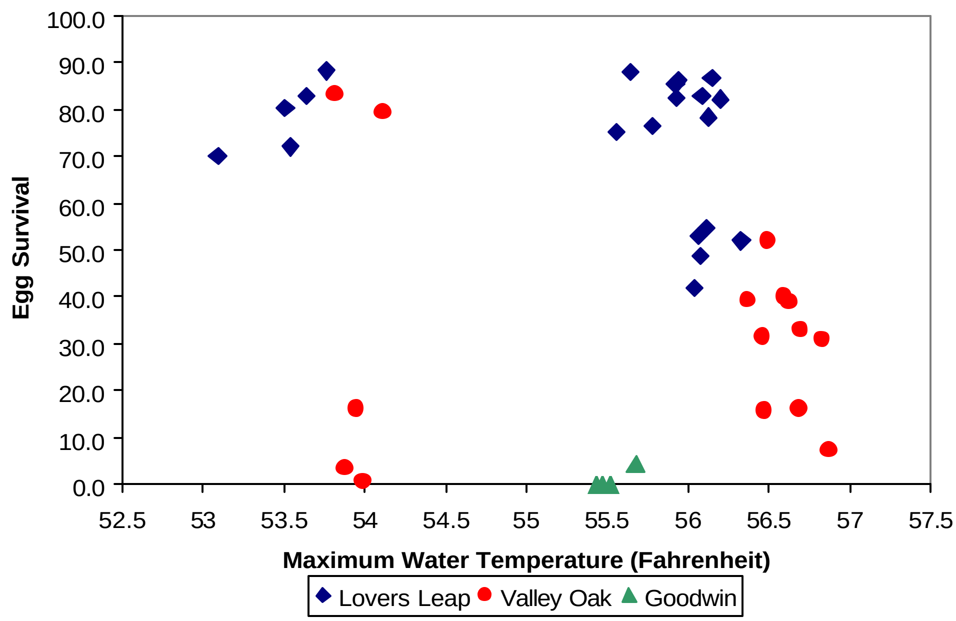


Figure 17. The percent of newly fertilized Chinook salmon eggs that survived relative to the maximum intragravel water temperature in artificial redds at the Goodwin Dam (DFG1), Lovers Leap (R19, R19A, and R20), and Valley Oak sites (R57 and R58) recorded with Onset thermographs between egg planting and egg hatching. The eggs exposed to the warmer temperatures were planted in November whereas the eggs exposed to cooler temperatures were planted in December. Salmonid egg survival decline as water temperatures exceed 57 degrees Fahrenheit under laboratory conditions (CMC 2002b).

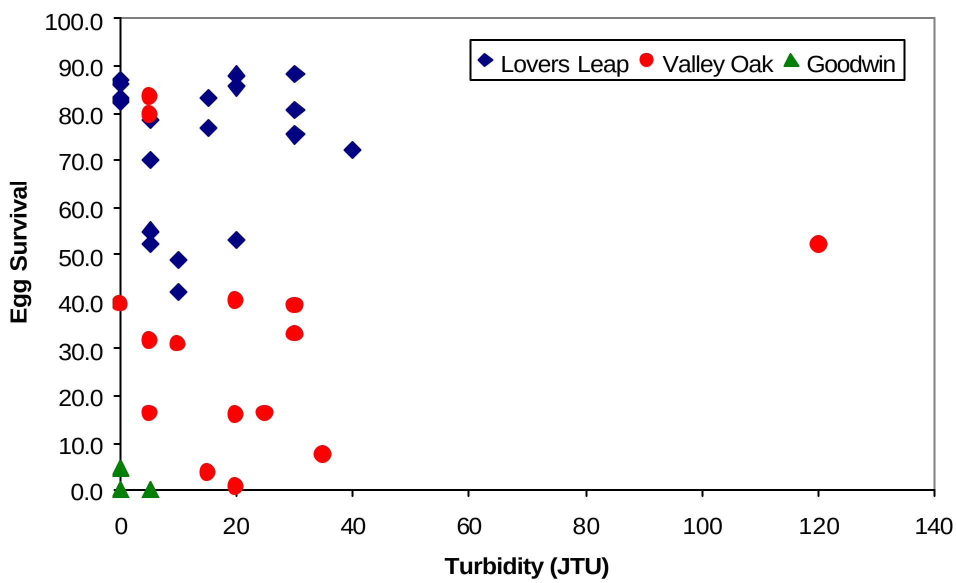


Figure 18. The percent of newly fertilized Chinook salmon eggs that survived relative to the intragravel turbidity measurements in artificial redds at the Goodwin Dam (DFG1), Lovers Leap (R19, R19A, and R20), and Valley Oak sites (R57 and R58) made in mid-January 2005 following several turbid storm runoff events.

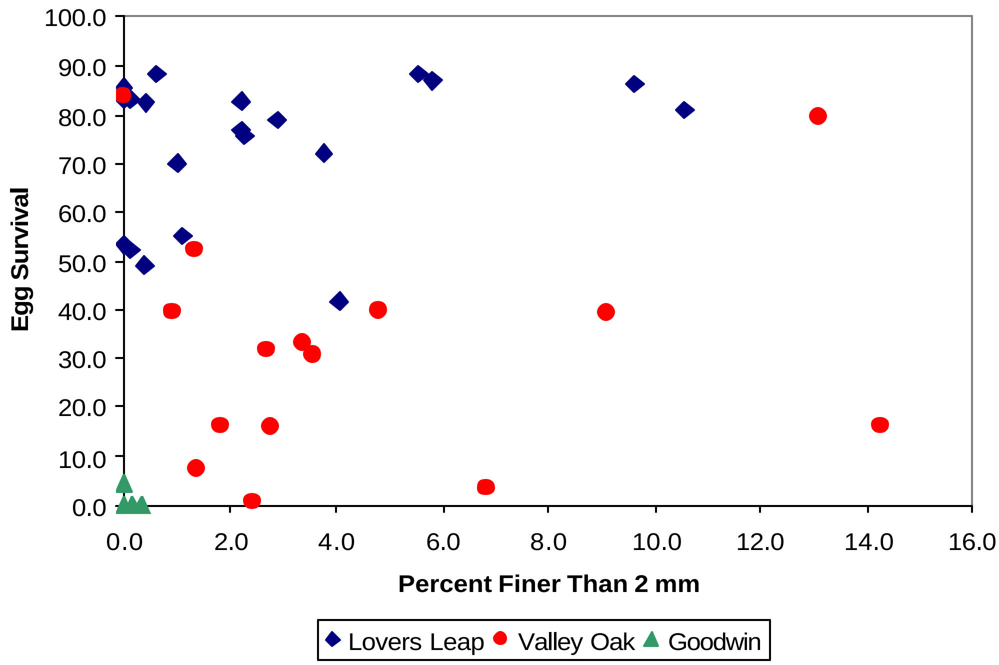


Figure **19**. The percent of newly fertilized Chinook salmon eggs that survived relative to the percentage of sediment particles finer than 2 millimeters in diameter in artificial redds at the Goodwin Dam (DFG1), Lovers Leap (R19, R19A, and R20), and Valley Oak sites (R57 and R58).

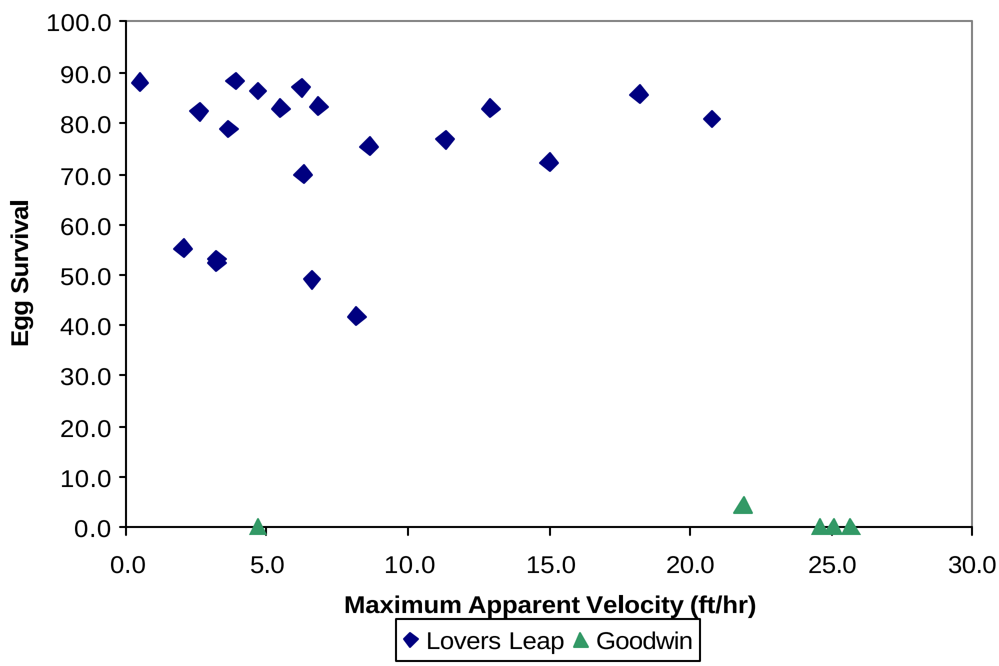


Figure 20. The percent of newly fertilized Chinook salmon eggs that survived relative to the maximum intragravel apparent velocity measurements in artificial redds at the Goodwin Dam (DFG1) and Lovers Leap (R19, R19A, and R20) sites that were made between egg planting and December 21, 2004, which was prior to egg hatching.

Turbidity, Fine Sediments, And Water Temperature

It is likely that egg survival at the downstream Valley Oak sites was affected by a combination of factors that individually would not have caused egg mortality, but in combination reduced egg survival from about 70% to about 30%. Although storm runoff at the Valley Oak sites had been quite turbid during the fall 1999 and fall 2000 studies, there was only a small difference in turbidity between the Lovers Leap sites (R19A and R20) and the Valley Oak sites in fall 2004. The effects of intragravel turbidity alone cannot explain why egg survival was only 30% for eggs planted on November 8, 2004 but was 80% and 84% at two of the five chambers planted on December 2, 2004, when both plantings of eggs were affected by the same turbid storm runoff in late December 2004 and early January 2005 (Figure 18; Table 7). A more plausible explanation is that the Valley Oak egg survival rates were affected by water temperatures that were near the threshold for egg survival between November 8 and 17 (Figure 17) in combination with the effects of clay-sized sediment that coated the eggs and further stressed them to the point that mortality occurred at normally sublethal temperatures. At the Lovers Leap sites, where egg survival rates were high, the eggs were not planted until November 12, 2004 and so the eggs were exposed to slightly lower temperatures for a shorter duration than those at the Valley Oak sites (Figure 21). The eggs planted at Valley Oak (R57) on December 2 were also exposed to relatively low temperatures and so survival rates at Chambers 1 and 3 of the December 2 planting were substantially higher (Table 7).

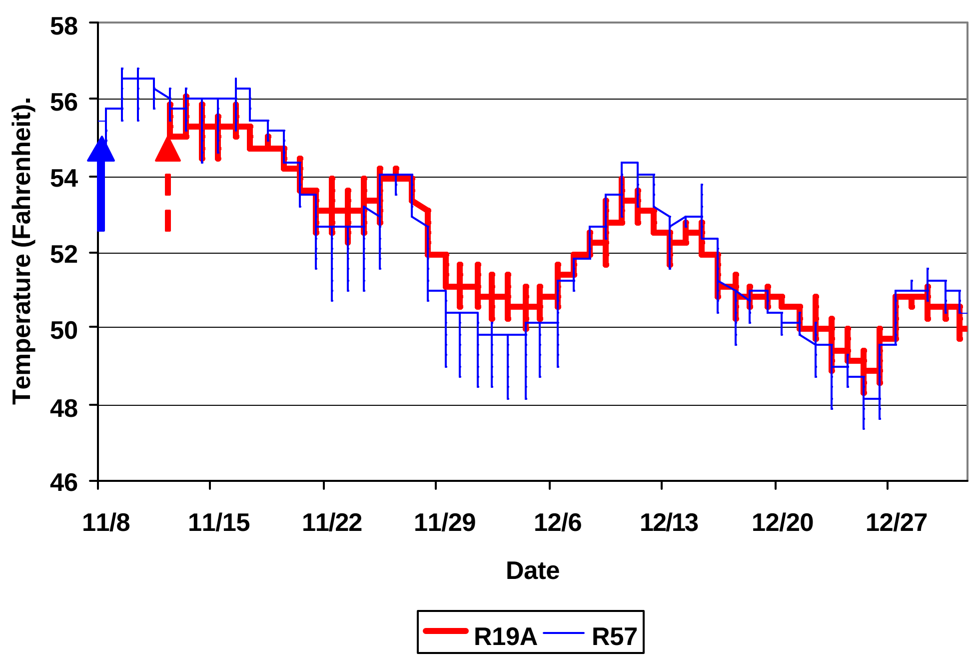
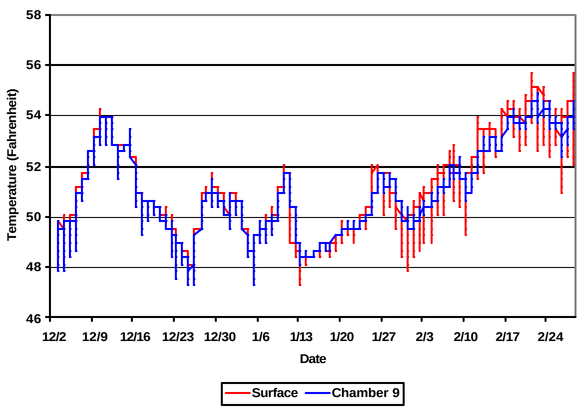


Figure 21. Intragravel water temperatures relative to surface water temperatures in November at egg chamber 1 in Riffle R57 where egg survival was 31% and egg chamber 1 in Riffle 19A where egg survival was 81%. The egg chambers were planted on November 8 at Riffle R57 (solid blue arrow) and on November 12, 2004 at Riffle R19A (dashed red arrow). The intragravel water temperatures at R57 and the other Valley Oak sites were slightly higher, high over a longer duration, and fluctuated more than those at R19A and the other Lovers Leap sites.

The unusually low egg survival rates at egg chambers 2 and 4 at Valley Oak that were planted on December 2 may be explained by relatively high concentrations of fines at those chambers. The estimated percentage of fines smaller than 2 millimeters was 14% at Chamber 2 (Figure 19). Although the measured percentage of fines at Chamber 4 was low (2%), the intragravel water temperatures were unusually stable at Chamber 4 in mid-January 2005 (Figure 22) suggesting that the amount of fines was sufficient to reduce the flow of surface water into the egg pocket; none of the other chambers had substantially elevated intragravel water temperatures for more than a few days. The minimum D.O. concentration at Chamber 4 was 8.3 ppm, which was near the threshold for egg survival in a silty environment (CMC 2002b), and it is possible that the eggs in Chamber 4 were exposed to low D.O. concentrations longer than were the eggs in the other chambers. None of the measured environmental parameters explain the low egg survival (3.4%) at Chamber 5 at Valley Oak that was planted on December 2, 2004.



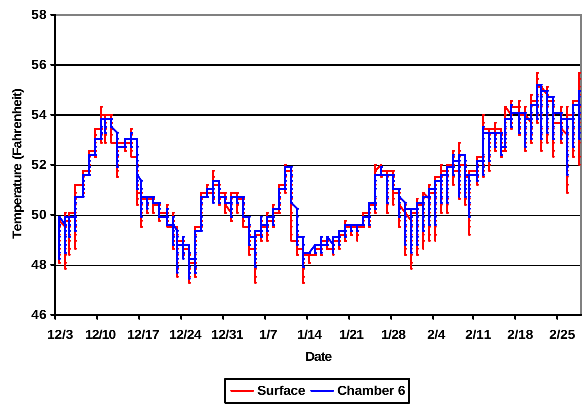


Figure 22. Intragravel water temperatures relative to surface water temperatures from December 2, 2004 to February 24, 2005 at egg chamber 4 (left plot) where egg survival was 0.6% and egg chamber 1 (right plot) where egg survival was 83.6%. These egg chambers were planted on December 2, 2004. The intragravel water temperatures at egg chamber 1 were typical for the egg chambers at all study sites except chamber 4 at R57. The relatively stable intragravel water temperatures at egg chamber 4 suggest that fines were reducing the flow of surface water into the egg chamber.

The percentage of particles smaller than 16 mm (Figure 23) and intragravel flow rates (Figure 24) at the Valley Oak sites were similar to those at Lovers Leap where egg survival rates were high. Therefore, near lethal fluctuating water temperatures, high turbidity, and fines that reduce the flow of surface water to the eggs are the most likely causes of the reduced egg survival at Valley Oak.

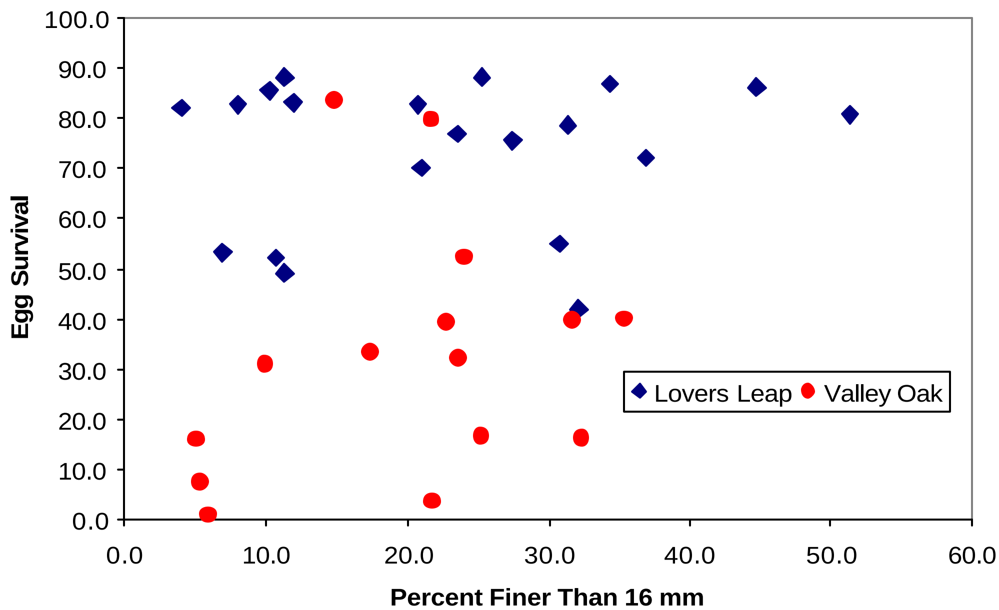


Figure 23. The percent of newly fertilized Chinook salmon eggs that survived relative to percentage of sediment samples from artificial redds that was finer than 16 mm at the Lovers Leap sites (R19, R19A, and R20) and Valley Oak sites (R57 and R58).

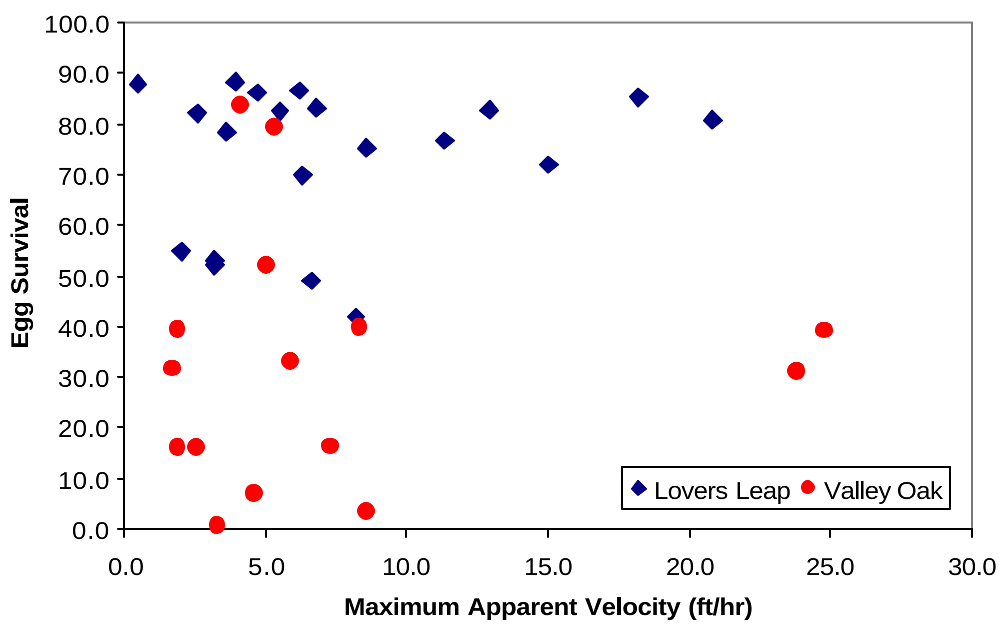


Figure 24. The percent of newly fertilized Chinook salmon eggs that survived relative to the maximum intragravel apparent velocity measurements in artificial redds at the Lovers Leap (R19, R19A, and R20) and Valley Oak sites (R57 and R58) that were made between egg planting and December 21, 2004, which was prior to egg hatching.

Effects Of Egg Source And Handling On Egg Survival

One potentially confounding factor for the fall 2004 egg survival studies is that the eggs planted in November in Goodwin Canyon and the Valley Oak sites, where egg survival rates were relatively low, were from a different female and planted on a different date than those planted at the Lovers Leap sites, where egg survival rates were relatively high. However, it is unlikely that egg survival during the fall 2004 studies was affected by the source of eggs or how the eggs were handled for three reasons. First, the survival of the eggs kept at the Merced River hatchery was high for all three females. Second, eggs were planted at Riffle 19A in Lovers Leap from two different females on two different dates and yet the eggs survival rates were nearly identical. Third, the same female's eggs were used at both the DFG1 site and the Valley Oak sites for the November 8, 2004 plantings and the egg survival rates were consistently moderate at the Valley Oak sites and consistently near zero at the DFG1 site. Therefore, it is highly likely that the egg survival rates were a response to the environmental conditions at the study sites.

ENTOMBMENT OF FRY IN SUPERIMPOSED REDDS

Hypothesis five states that entombment of Chinook salmon fry at naturally occurring redds will be significantly greater when redds are superimposed than not. Because most of the 2-7 mm diameter sand that creates a natural sand barrier within a redd and affects entombment rates had been eliminated from restoration gravel in 1999 (CMC 2001) entombment rates were expected to be lower at the restoration sites than in the control sites.

To investigate this hypothesis, 10 superimposed and 12 non-superimposed natural redds were excavated at ten riffles in March 2005. The results indicate that overall entombment rates were low (13.6% of the redds) and no entombed fry were collected from superimposed redds (Figure 25). The fall 2004 fry entombment rates were much lower than those observed during the fall 2000 studies (CMC2002c), when escapement was almost double the fall 2004 estimate. In fall 2000, 31.6% of the superimposed redds and 16.7% of the non-superimposed redds contained entombed fry (CMC 2002c).

In fall 2004, the cumulative percentage of sediment particles finer than 2 millimeters was higher in superimposed redds than in non-superimposed redds (Table 9). This suggests redd superimposition would be expected to increased fry entombment rates and perhaps this would have been the case if a greater number of redds had been examined. However, the differences observed in fall 2004 were not statistically significant ($p \geq 0.21$) for comparisons between superimposed and non-superimposed redds and for comparisons between natural and restoration gravels due to the low number of samples taken.

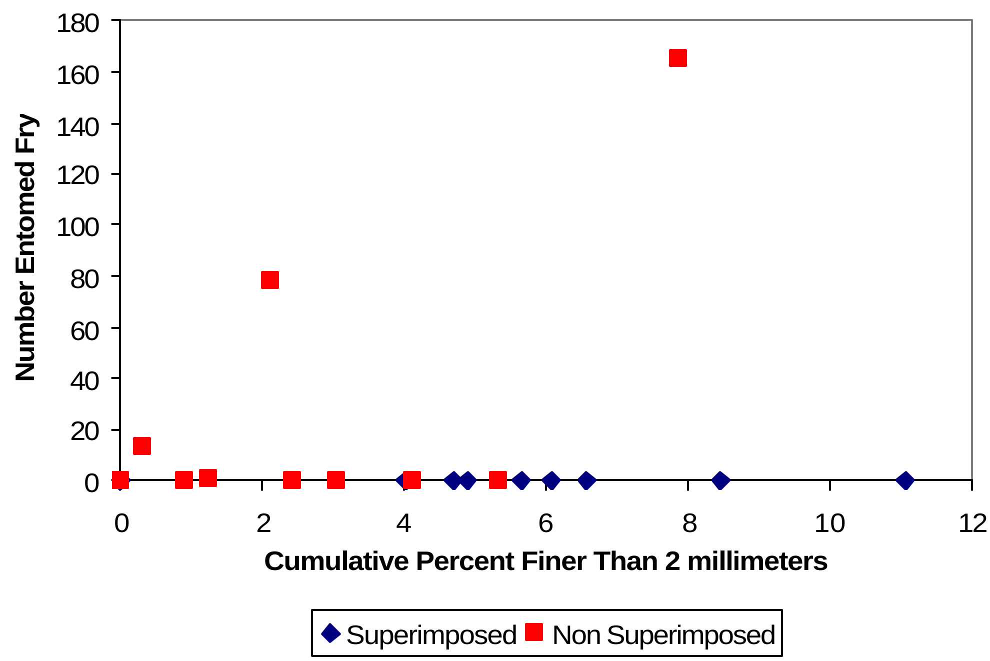


Figure 25. The number of entombed fry (live and dead) in 10 superimposed and 12 non-superimposed natural redds in 10 KFGRP sites relative to the concentration of fines in the redd.

Table 9. The mean cumulative percentage of substrate particles finer than 2 millimeters in natural superimposed and non-superimposed redds in natural and KFGRP restoration gravels in the Stanislaus River.

Redd and Gravel Type	Number of Redds with Entombed Fry (No. of Fry)	Mean cumulative Percent Finer Than 2 mm	Sample Size
Superimposed in KFGRP Restoration Gravel	0	4.39%	6
Superimposed in Natural Gravel	0	6.28%	4
Non-Superimposed in KFGRP Restoration Gravel	1 (78)	1.92%	10
Non-Superimposed in Natural Gravel	2 (178)	4.10%	2

SEDIMENT SCOUR FROM RESTORATION SITES

To evaluate Hypothesis 7, *Riffles Constructed In Widened, Mined Channels Will Have A Longer Useful Life Than Would Riffles Constructed In Narrow Unmined Channels*, the project sites were mapped in fall 2004 and digital terrain models were compared over time to estimate the change in bed volume. Mapping the contours of the 18 project riffles was relatively difficult in fall 2004 because the streambed developed a rough surface as the salmon gradually moved gravel into alternating rows of mounds and depressions as they constructed their redds over the four years since the spawning beds were constructed. This would explain why the bed elevations along the permanent transects in the middle of the sites increased at most of the project sites in fall 2004. As examples of sites with relatively large shifts of gravel within the site, plots of the elevations at the permanent transects are shown for riffles R1 (Figure 26) and R14A (Figure 27).

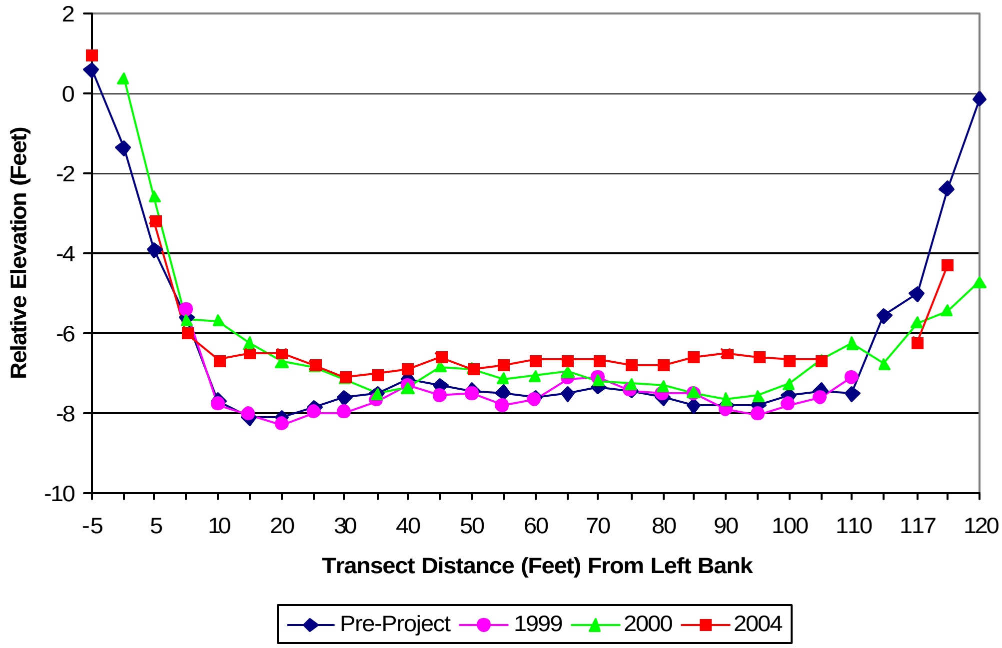


Figure 26. Plot of the streambed elevations at the permanent transect at Riffle R1 for pre-project conditions in August 1998 and post-project conditions in fall 1999, 2000, and 2004. The digital terrain model indicated that the bed volume increased by 81.2 cubic yards between fall 2000 and fall 2004.

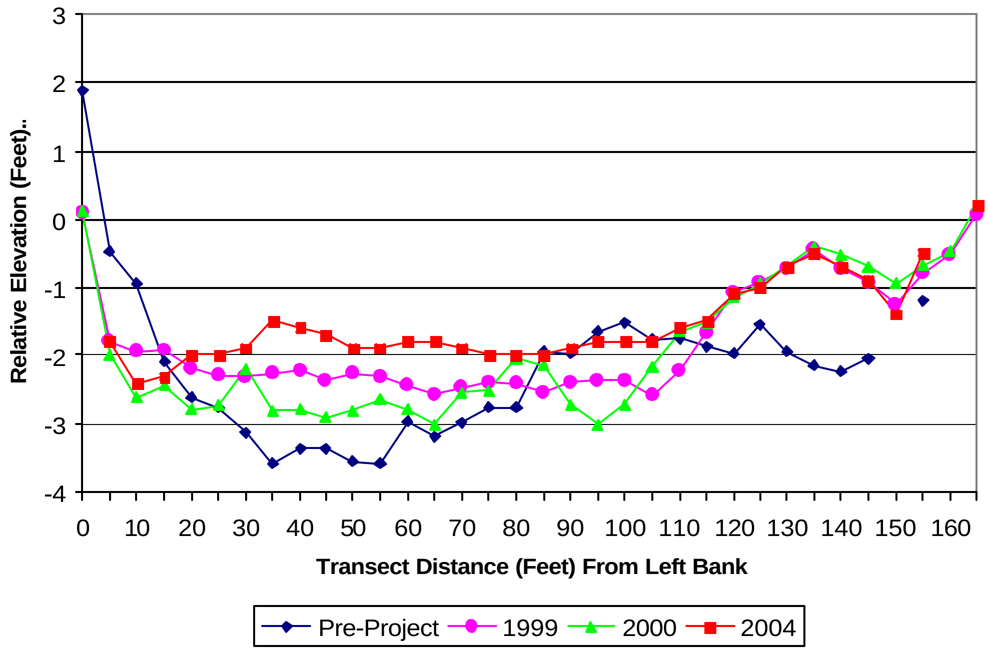


Figure 27. Plot of the streambed elevations at the permanent transect at Riffle R14A for pre-project conditions in August 1998 and post-project conditions in fall 1999, 2000, and 2004. The digital terrain model indicated that the bed volume increased by 197.5 cubic yards between fall 2000 and fall 2004.

Although a reasonable effort was made to map all the mounds and depressions in the bed surfaces, the digital terrain models unexpectedly indicated that the fall 2004 bed elevations were higher in fall 2004 than in fall 2000 (Table 10). The volumes were also unexpected high compared to the mean gravel volume of 29.4 cubic yards per site that moved between winter 1999 and fall 2000 (CMC 2002c), when flows were high (Figure 28). Large depositions of gravel between fall 2000 and 2004 are highly unlikely as there was no substantial source of gravel recruitment for any of the project sites and there were no high flows that could have transported the gravel (Figure 28). Instead, we interpret the model analysis to indicate that there was no substantial change in gravel volume at any of the KFGRP riffles.

Table 10. The volume and size of the gravel placed in summer 1999, the volume mobilized between September 2000 and September 2004, and percent of the total gravel placed that was mobilized between September 2000 and September 2004 for the 18 Knights Ferry Gravel Replenishment Project sites. Positive estimates of gravel mobilized indicate a net fill and negative estimates indicate a net cut.

Riffle #	Rivermile	Channel Width	Gravel Plant Screen Size	Placed Cubic-Yards	Mobilized Cubic-Yards	% Mobilized
TMA	56.8	56.8	1/4-inch	470	-156.3	-33.3%
R1	54.55	107	3/8-inch	395	81.2	20.6%
R5	53.9	81	3/8-inch	315	23.3	7.4%
R12A	52.82	141	3/8-inch	380	35	9.2%
R12B	52.77	111	1/4-inch	470	66.1	14.1%
R13	52.73	113	3/8-inch	860	39.6	4.6%

Riffle #	Rivermile	Channel Width	Gravel Plant Screen Size	Placed Cubic-Yards	Mobilized Cubic-Yards	% Mobilized
R14	52.6	109	1/4-inch	465	99.4	21.4%
R14A	52.57	106	3/8-inch	1,055	197.5	18.7%
R15	52.51	170	3/8-inch	610	146.6	24.0%
R16	52.48	165	3/8-inch	240	-40.6	-16.9%
R19	52.13	121	1/4-inch	130	22.6	17.4%
R19A	52.06	109	3/8-inch	680	17.2	2.5%
R28A	50.2	96	1/4-inch	250	9.6	3.8%
R29	49.75	104	3/8-inch	210	45.3	21.6%
R43	46.9	92	3/8-inch	315	12.2	3.9%
R57	44.6	87	3/8-inch	645	No data	--
R58	44.5	102	1/4-inch	465	90.6	19.5%
R76	40.2	90	3/8-inch	405	32.4	8.0%

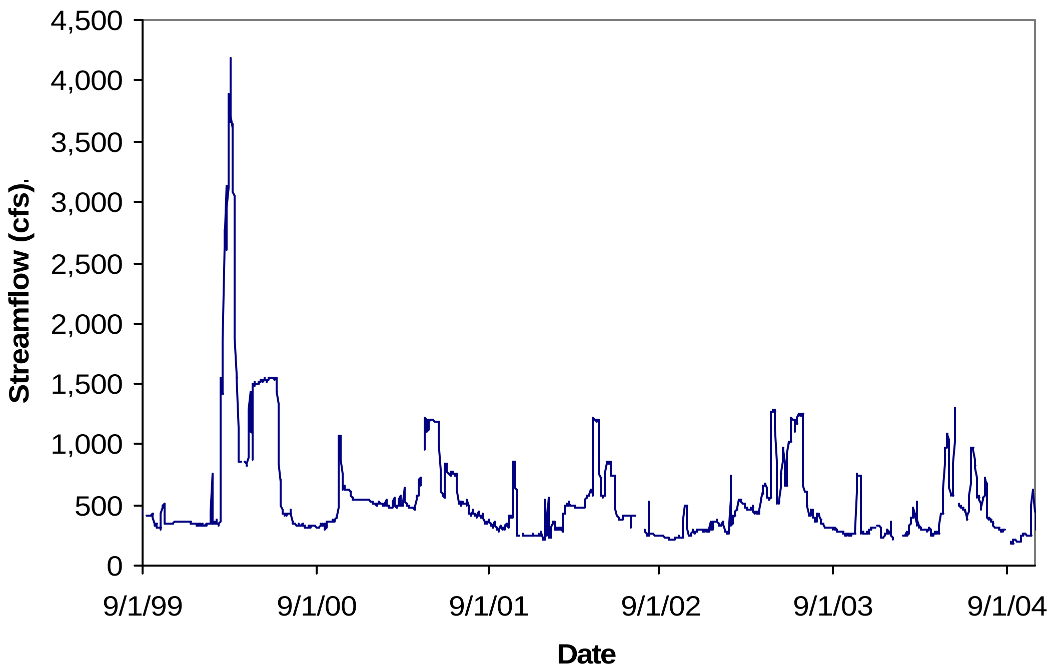


Figure 28. Estimated streamflow at the Orange Blossom Bridge gage in the Stanislaus River (Rivermile 46.9) from September 1, 1999 to October 31, 2004. Data was obtained from the California Data Exchange Center web site [http://cdec.water.ca.gov/].

CONCLUSIONS

Overall, the Phase II studies indicate that the construction of spawning beds for fall-run Chinook salmon with clean spawning gravels in the Stanislaus River provides short-term benefits for spawning and egg incubation and perhaps longer term reductions in fry entombment that would otherwise be caused by excessive amounts of fine sediments (< 2 mm). Most of the habitat degradation occurred between fall 2000 and fall 2004 when no flood control releases were made below Goodwin Dam. Specific analyses suggest that adding gravel cleaned with a 1-inch screen could substantially reduce egg survival rates and adding gravel from other watersheds (e.g., Tuolumne River) could immediately degrade the spawning habitat, although the detrimental effects of using non-native gravels were not apparent after 12 months. The egg survival studies also suggest that egg survival in the downstream reaches may have been reduced by the combined effects of near lethal water temperatures that fluctuated greatly in early November, excessive fines that reduce dissolved oxygen concentrations, and intragravel turbidity that presumably coated the eggs with clay-sized particles that reduced the egg's abilities to absorb oxygen. The seven hypotheses are evaluated below with the data collected during the fall 2004 Phase II studies as well as the Phase I studies:

Hypothesis 1: *Chinook Salmon Spawners Prefer To Use Native Stanislaus River Rock Compared To Imported Rock From The Tuolumne River* was true for only the first few years. The density of fall-run Chinook salmon redds was significantly higher in native Stanislaus River rock than in Tuolumne River rock in fall 1999 (CMC 2002b) and fall 2000 (CMC2002c), but not in fall 2004. The increased use of the non-native Tuolumne Rock over the first 12 monts is probably a result of the deposition of native sediment onto the restoration site. Therefore, it may be possible that mixing a small amount of native rock with non-native rock for spawning bed construction would result in high initial use by salmon spawners. On the other hand, the sites with the Stanislaus River rock degraded to the point that spawner use was equal to the spawner use at the degraded control sites within five years after construction. The gradual reduction in redd density at the sites with Stanislaus River rock was probably due to the gradual armoring of the bed's surface (loss of smaller particles) as well as fine sediment intrusion that compacted the beds and therefore made it more difficult for the salmon to construct their redds.

Hypothesis 2: *Chinook Salmon Spawners Prefer To Use Gravel Cleaned With A 1/4-Inch Screen And A 5-Inch Grizzly Compared To Gravel Cleaned With A 3/8-Inch And A 5-Inch Grizzly* was rejected. There were no statistically significant differences in the density of fall-run Chinook salmon redds in gravel cleaned with a 1/4-inch or a 3/8-inch screen during any of the post-project surveys conducted in fall 1999 (CMC 2002b), fall 2000 (CMC 2002c) or fall 2004.

Hypothesis 3: *Adding Gravel Without Fines To The Streambed Increases Intragravel D.O. Concentrations And Intragravel Flow Rates Compared To Those At The Control Riffles* was true for intragravel D.O. concentrations during only the first few years, but true for intragravel flow rates and a low amount of fine sediments throughout the duration of the five-year study period. Streambed permeabilities in undisturbed gravels, which provide an index of intragravel flow and the amount of fines, were significantly higher in restoration sites than in natural control sites during all the post-project surveys conducted in fall 1999 (CMC 2002b), fall 2000 (CMC 2002c), and fall 2004; although they declined rapidly in the restoration sites from 1999 to 2004. Intragravel flow rates were also significantly higher at the restoration sites compared to the control sites in fall 2000 (CMC 2002c); however, flow rate trends could not be evaluated because apparent velocity measurements were only taken at all of the study sites in fall 2000. As for intragravel dissolved oxygen concentrations, they were only significantly higher in artificial redds constructed in restoration sites than in control sites in fall 1999 immediately after construction (CMC 2002b, 2002c). The most direct metric for evaluating whether KFGRP riffle construction increased the production and health of salmon fry is provided by the rotary screw trap studies in the Stanislaus River near Oakdale (RM 40) conducted by Cramer Fish Sciences, Oakdale, California. Their rotary screw trap studies suggest that the abundance of juvenile salmon migrating from the spawning reach was relatively high during the first two years after project implementation, but then dropped to pre-project levels in four out of the next five years through spring 2006 (Figure 2). Therefore, it is likely that the influx of large volumes of fine sediment into the restored KFGRP spawning beds rapidly degraded the quality of the habitat for egg incubation and/or the emergence of fry from the redds.

Hypothesis 4: *Restoring Riffle Habitat With Clean Gravel Will Increase Egg Survival And The Size Of Fry Compared To Control Riffles* would be rejected based on the results of the fall 2004 study alone. The percentage of eggs that survived to the fry stage in incubation chambers was relatively high at the KFGRP restoration sites at Lovers Leap, but not statistically different from the nearby control site where the gravel bed was armored and the bed permeability was moderate. However, the egg survival rates were near zero at a restoration site with gravel cleaned with a 1-inch screen, presumably because the interstitial spaces were too large which allowed the eggs to be excessively agitated at relatively moderate intragravel flow rates. To more fully test Hypothesis 4, additional research is needed to:

1. determine egg survival rates in more typical unrestored sites in the Stanislaus River, most of which have high concentrations of fines;
2. determine egg survival rates in gravels cleaned with intermediate sized screens (e.g., 1/2-inch and 3/4-inch screens); and
3. determine whether egg mortality in gravels cleaned with a 1-inch screen is due to excessive intragravel flow rates or excessive agitation of the eggs in the large interstitial spaces.

Hypothesis 5: *Entombment Of Fry Is Significantly Greater At Superimposed Redds Than In Non-Superimposed Redds* would be partially rejected based on the results of the fall 2004 study alone. A potential benefit of adding clean gravels for spawning is that the lack of fine substrates (< 2 mm) might reduce the rate that fry are entombed in their redds. High rates of fry entombment were observed during the fall 2000 study (CMC 2002c) but not in fall 2004. However, the fall 2004 studies did provide preliminary evidence that the percentage of fines in actual salmon redds was slightly lower in restoration sites than in natural gravels. To more fully test Hypothesis 5, additional studies are needed to evaluate fry entombment relative to the amount of fines in a greater number of redds over a wide range of gravel types.

Hypothesis 6: *Survival Is Significantly Lower For Eggs Exposed To Turbid Storm Runoff* was partially rejected. The reduced survival rates observed at the downstream Valley Oak sites were best explained by the combined effects of near lethal and highly fluctuating water temperatures in early November, high percentages of fine sediments (< 2mm), and high intragravel turbidity. Laboratory studies are recommended to facilitate the control and measurement of water temperature, turbidity, D.O. concentration, percentage of fine sediments, gravel size (interstitial pore size in the streambed), and intragravel flow rates.

Hypothesis 7: *Riffles Constructed In Widened, Mined Channels Will Have A Longer Useful Life Than Will Riffles Constructed In Narrow, Unmined Channels* was rejected based on the fall 2000 study (CMC 2002c). In fall 2000 after flows up to 3,500 cfs had occurred, the mean volume of gravel mobilized from riffles in narrow, unmined channels was 0.254 cubic years of gravel per square yard of spawning bed area. In contrast, the mean volume of gravel mobilized in widened mined channels was 0.099 cubic yards of gravel per square yard of spawning bed area (CMC 2002c). The differences were not significant probably because there were local conditions (e.g., bridge pillars and large trees on the riverbank) that affected the scour rate at some sites (CMC 2002c). Streamflows between fall 2000 and fall 2004 were not high enough to mobilize a substantial amount of gravel at the restoration sites.

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